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AFRPL-TR-69-106

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DESIGN AND DEVELOPMENT OF STORABLE PROPELLANT TANKS

Thomas J. O'Grady

THIOKOL CHEMICAL CORPORATION
REACTION MOTORS DIVISION

TECHNICAL REPORT AFRPL-TR-69-106

June 1969

AIR FORCE ROCKET PROPULSION LABORATORY
RESEARCH AND TECHNOLOGY DIVISION
AIR FORCE SYSTEMS COMMAND
EDWARDS AIR FORCE BASE, CALIFORNIA

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Thomas J. O'Grady

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FOREWORD

The work documented in this report was accomplished by the Reaction Motors Division of Thiokol Chemical Corporation, Denville, New Jersey, in compliance with United States Air Force Contract No. F04611-68-c-0082. It was administered under the direction of the Air Force Rocket Propulsion Laboratory, Edwards Air Force Base, California, with 1st Lt. Richard Mears, USAF/RPRPT, acting as Project Engineer.

This Final Report describes the tasks accomplished from contract award in May 1968, to contract completion in March 1969.

Reaction Motors Division performed the contract under the direction of Mr. L. M. Bachman, Program Manager, with Mr. T. J. O'Grady acting as Project Engineering Supervisor. Mr. C. Nash was the Project Stress Engineer, Mr. C. R. Jacobus the Welding Engineer, and Mr. S. Kahn the Quality Assurance Representative. Mr. A. Hallock acted as the Prime Manufacturing Coordinator, and Mr. W. Riebesell as Buyer for subcontracted components.

This technical report has been reviewed and is approved.

Mary M. Racovich
AF Contracting Officer
Procurement Division
Directorate of Materiel

ABSTRACT

A maintenance-free propulsion system is desirable and may be required for future USAF missiles. A primary factor in achieving this goal is reliable, long-term containment of liquid rocket propellants in flightweight tanks. Further, the requirement also exists to positively expel these propellants during missile operation. This report describes the results of a program to design, evaluate and deliver full scale, flight-weight positive expulsion propellant tank systems for inclusion in the AFRPL storability program. The tank system has a diameter of 30 inches, an overall length of 43.4 and is sized for a total capacity of 1100 pounds of N_2O_4. The cylindrical design is comprised of a maraging steel (250 grade) outer shell inside of which is installed a all-aluminum Rolldex (rolling diaphragm) positive expulsion system. The Rolldex expulsion system consists of cylindrical inner and outer diaphragms, an annular piston with integral hub guide, and a convex dome. The outer and inner diaphragms are bonded to the tank wall and center support tube, respectively. During expulsion, the annular piston traverses the full length of the tankage, rolling the diaphragms as it goes and thus parting the bonds. The center tube provides a guide for the piston hub and takes out asymmetric piston loads which may arise under certain operating conditions. Diaphragm displacement during storage is prevented by the bonding. Piston displacement is prevented by provision of a vacuum on the gas side of the piston to positively lock the piston against the steel head. All materials of construction are compatible with N_2O_4 for long term storage. The materials used are 1100-0 and 6061-T6 aluminum, 250 grade maraging steel and Teflon. A succession of barriers throughout the assembly eliminates the possibility of leakage. Special provisions are made at the fill and load ports to prevent leakage at these points. Detailed thermal and structural analyses were performed, as well as laboratory tests to verify critical design parameters. A test phase was conducted, consisting of a successful hot gas expulsion test to demonstrate the design under operational environments, followed by fabrication and delivery of units for inclusion in the AFRPL storability program.

CONTENTS

ILLUSTRATIONS

TABLES

SECTION I

INTRODUCTION

This report is submitted as the Final Technical Report under Air Force Rocket Propulsion Laboratory (AFRPL) Contract No. FO4611-68-c-0082 to the Reaction Motors Division of Thiokol Chemical Corporation. The objective of the program, the results of which are described in this final report, were the design, evaluation and delivery of full-scale flight-weight, positive expulsion propellant tank systems for inclusion in the AFRPL Storability Program. This report describes the effort conducted by Thiokol-RMD during the period from 1 May 1968 through 1 March 1969.

The approach selected for development to fulfill the specified AFRPL requirements for both long term storage and positive expulsion of propellants was to utilize an aluminum rolling metal bladder (termed Rolldex by Thiokol-RMD) expulsion system housed in a maraging steel tank shell. The significant features and advantages of the Rolldex expulsion concept are:

- Hermetically seals the propellants during storage and expulsion
- Provides high volumetric efficiency
- Provides high 99% expulsion efficiency
- Provides positive control of liquid location during expulsion (predictable c.g. shift)
- Is completely compatible (through proper material selection) with a variety of propellants; and further, permits the use of non-compatible tankage materials if desired, since propellants are stored in the containers formed by the Rolldex and are not in contact with the tank structure
- Inherently prevents movement of the Rolldex diaphragm (through bonding to the tank structure) providing shock and vibration capability during storage, transportation and handling.

An overall view of the positive expulsion tank assembly which was successfully developed and delivered to AFRPL is shown on Figure 1. The tank assembly has a diameter of thirty (30) inches and is sized for a total capacity of 1100 pounds of N_2O_4.

The subsequent sections present the detail results of the design, fabrication and test effort.

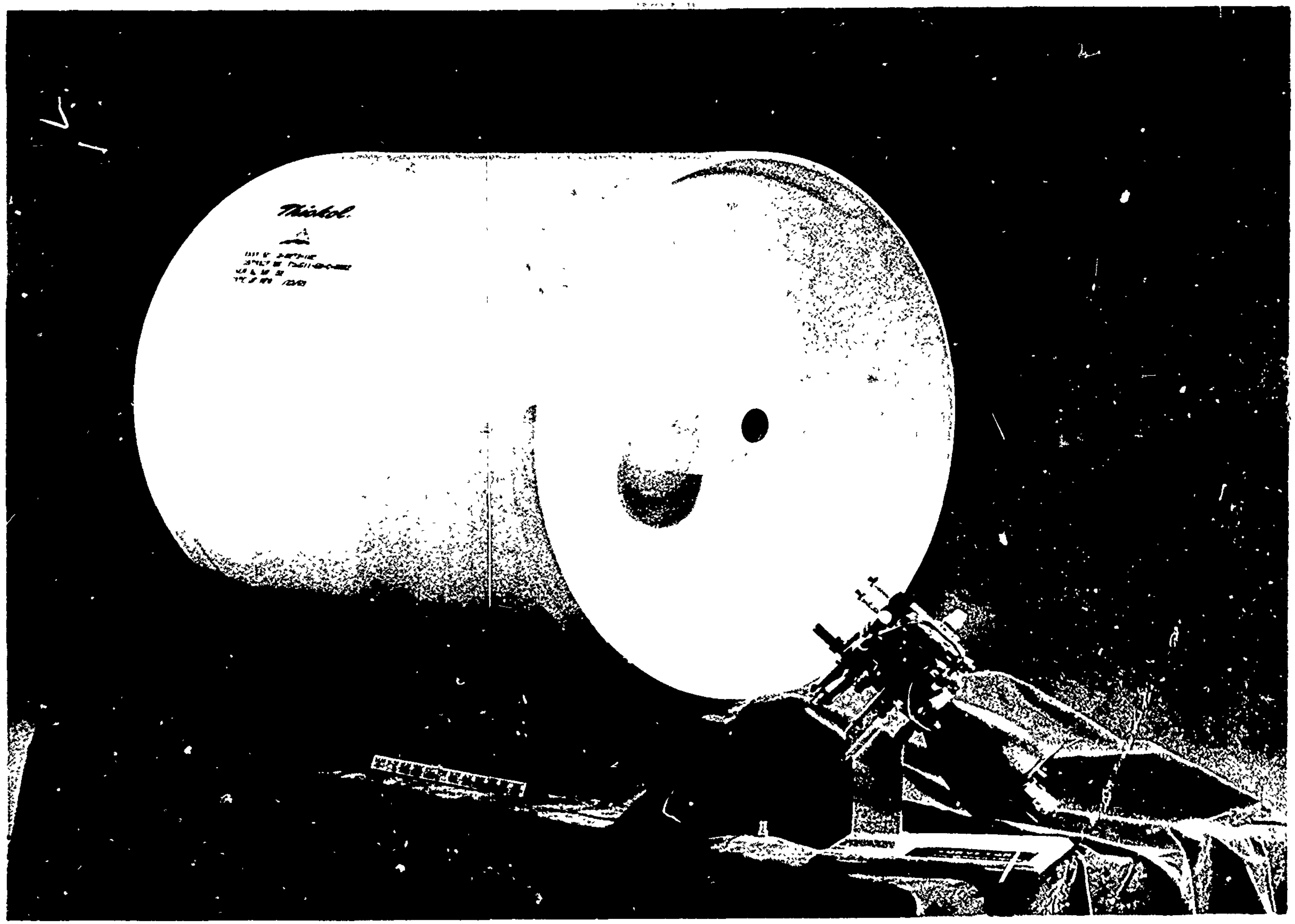


Figure 1. N_2O_4 Positive Expulsion Tank Assembly

SECTION II

DESCRIPTION AND DESIGN SUMMARY

1. REQUIREMENTS

The specified design requirements for the positive expulsion tank assembly all of which were met or exceeded, are summarized below:

TANK DESIGN REQUIREMENTS

Shape:	Cylinder
Capacity (loaded)	1100 lb N_2O_4
Diameter:	30 inches
Propellant:	Nitrogen Tetroxide (N_2O_4)
Temperature:	
Storage (empty)	-65 to +150°F
(loaded)	+40 to +120°F
Operating (External)	+30 to +500°F
Propellant Leakage:	NONE: Conformance to this requirement to be demonstrated by the conduct of helium leakage tests.
Pressure:	
Storage:	Propellant Vapor Pressure
Operating (External)	0 to 20 psia
(Internal)	400 psia
Actuation:	10 psid (max)
Propellant Expulsion Efficiency:	98% (min)
Volumetric Efficiency:	95% (min)
Storage Life: (Loaded)	5 years (min) 10 years (goal)
Mission Life:	15 minutes (max)
Propellant Flowrate:	0 to 5 lb/sec
Acceleration:	23 g's (max)
Vibration:	See Figure 2
Shock:	See Figure 3

Other significant design criteria and/or assumptions on which the design was based are as follows:

- Propellant Expulsion Efficiency Definition

$$\text{Expulsion Efficiency} = \frac{\text{Volume of Propellant Expelled}}{\text{Volume of Propellant Loaded}} \times 100$$

- Propellant Volumetric Efficiency Definition

$$\text{Volumetric Efficiency} = \frac{\text{Volume of Propellant Expelled}}{\text{Internal Volume of Tank Shell}} \times 100$$

Of major significance was the requirement for zero liquid propellant leakage to be demonstrated by the conduct of helium leak tests. Further, it was required that all parts of the tank assembly in contact with propellant during storage be metal, that all joints in contact with propellant be welded, and that no bi-metallic joints be used in the propellant system.

All of the above requirements were met or exceeded as discussed in the subsequent sections of this report.

2. DESCRIPTION

An assembly drawing of the N_2O_4 Positive Expulsion Tank Assembly which was developed and delivered to the AFRPL for loading with propellant and storage is shown on Figure 4. Figure 1 of this report provides an overall view of a completely assembled unit. The unit is comprised of a cylindrical tank with a conventional dished head at the aft (propellant outlet) end and an inverted dished head at the forward end and has an outside diameter of 30 inches and an overall length of 42.4 inches. This end closure configuration provides the most efficient structure in combination with contours which will permit nesting of the expulsion piston at each end of the tank to maximize both volumetric and expulsion efficiencies. The structural shell of the tank is of all welded construction and is fabricated of Grade 250 maraging steel. The final closure weld of the tanks is made at the aft end at the joint between the cylindrical wall and the periphery of the header after installation of the Rolldex expulsion system. The wall thicknesses have been increased locally at this joint as the strength at this location will be in the "as welded" condition.

The Rolldex expulsion system consisting of the outer and inner diaphragms, the aft dome section, and the actuating piston is fabricated completely of aluminum. The outer and inner diaphragms are of 0.040 thick 1100-0 aluminum. The actuating piston and aft dome are constructed of 6061 aluminum as is the center boss at the aft end of the unit which contains the fill ports and propellant outlet port and passages. The expulsion system is a completely hermetically sealed, welded assembly. The outer diaphragm is bonded to the tank shell and the inner diaphragm bonded to the center support tube, using a Teflon bonding technique developed at Thiokol-RMD, to form a complete

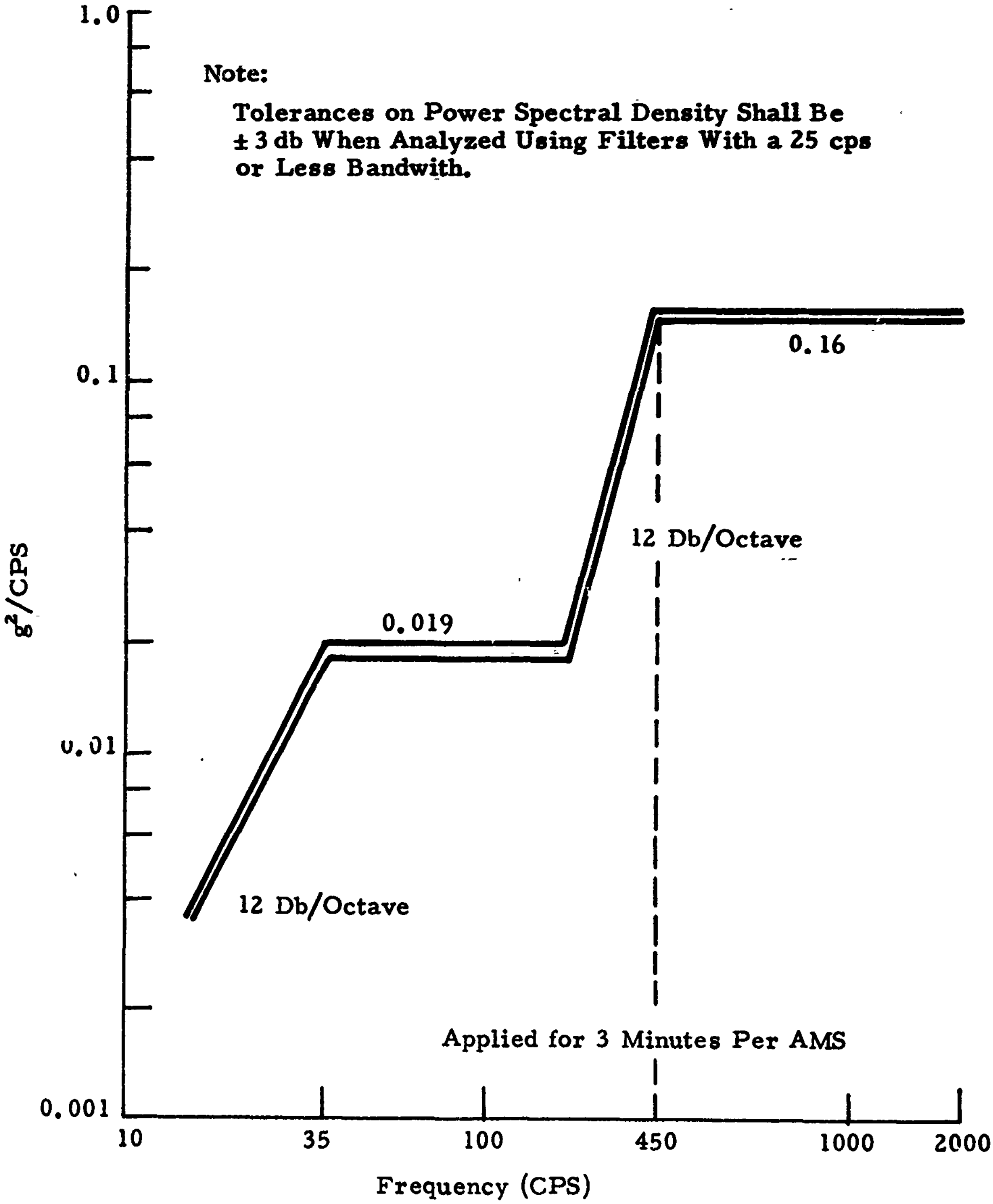


Figure 2. Vibration Environment

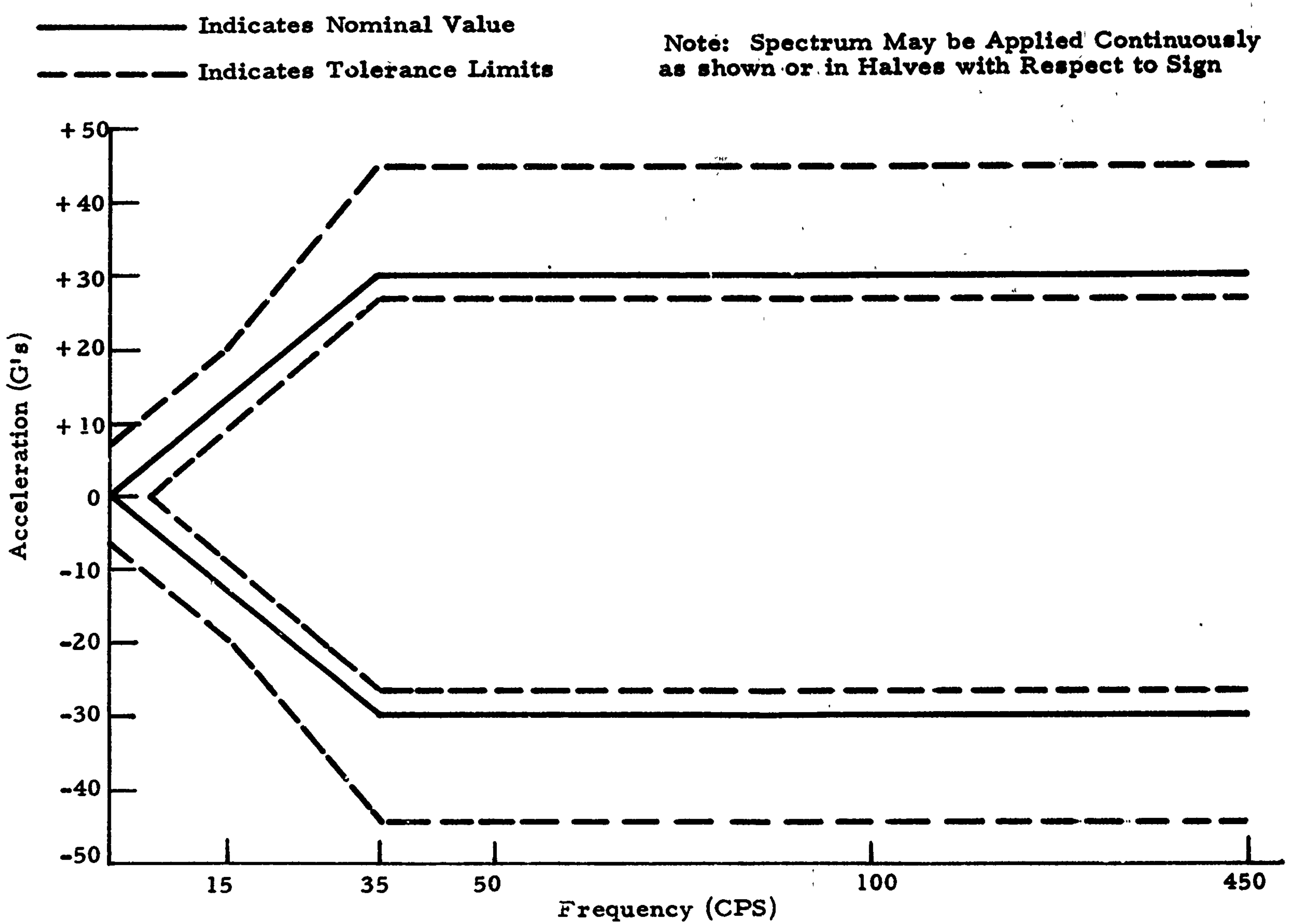


Figure 3. Shock Environment

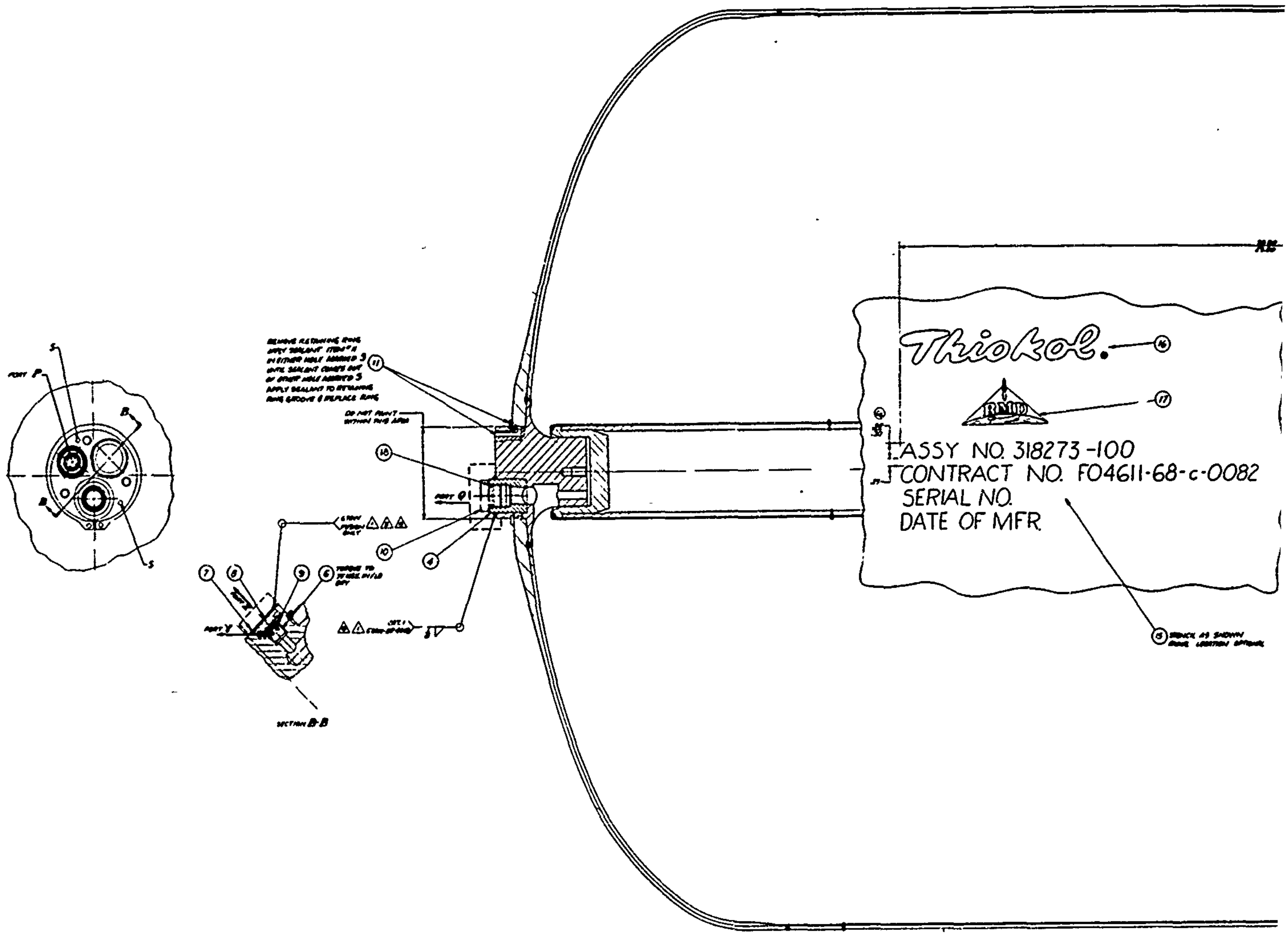
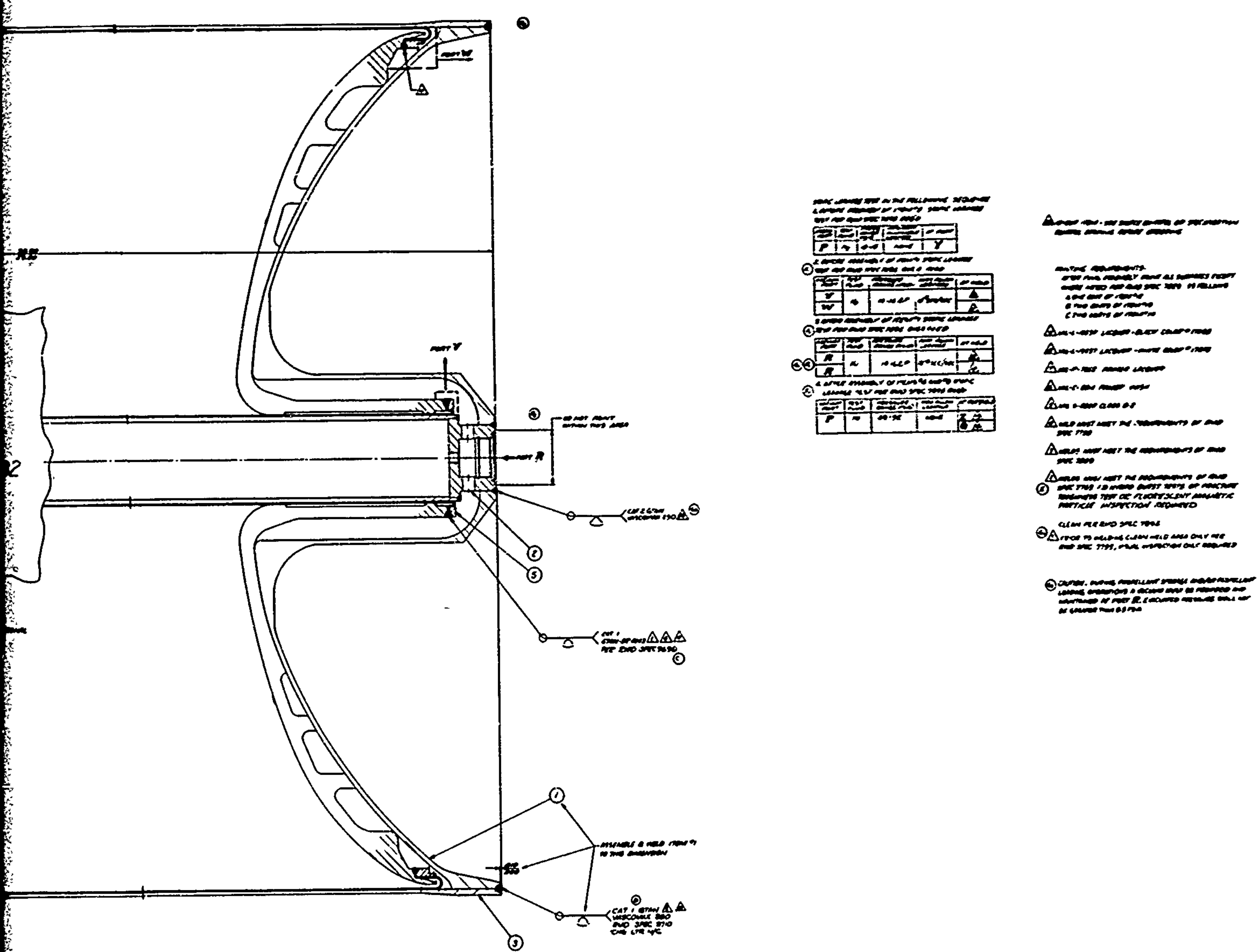


Figure 4. N_2O_4 Positive Expulsion Tank Assembly (Dwg 318273)

A



B

aluminum liner within the steel tank. As a result, the propellant is contained and sealed completely within the aluminum expulsion system and there are no bimetallic joints or elastomeric compounds in contact with the stored propellant.

The center tube on the longitudinal centerline of the tank provides support to the inner Rolldex diaphragm and also acts as a guide surface for the Rolldex piston to prevent cocking of the piston as a result of side loads during operation. The center tube is fixed in position at the aft end of the tank and secured by the bonding of the inner diaphragm. However, at the forward end the tube is restrained against movement only in the radial direction to allow freedom for axial movement in the event of any differential thermal expansion conditions which may occur during expulsion operations.

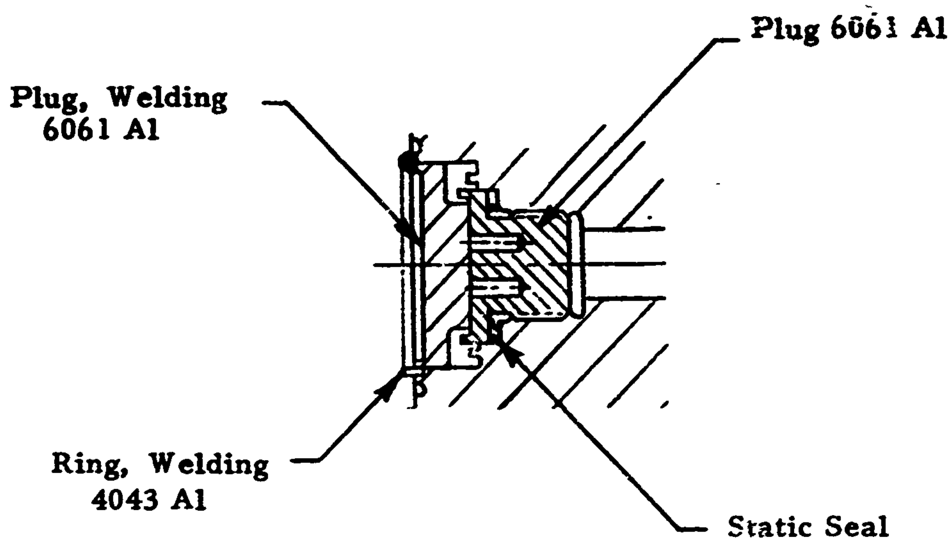
The tank design is based on provision of a vacuum on the gas side of the piston during storage to prevent movement of the piston due to atmospheric to propellant vapor pressure differentials which exist across the piston during storage. Provision of a vacuum also provides complete support for the piston against acceleration, vibration, and shock loadings which may occur during handling, shipping, or storage.

Small axial holes are machined on the inner diameter of the piston hub to assure fluid entry into the rolled portion of the inner diaphragm. This obviates a potential low pressure region here which, if it occurred, would result in a large differential buckling pressure on the rolled inner diaphragm. It also provides liquid cooling for the rolled inner diaphragm.

The tankage is sized for a capacity of 1100 lb of N_2O_4 with an allowance for 1/2 percent (nom) ullage volume in excess of the volume required by the N_2O_4 at 120F storage temperature. The 1/2 percent is based upon experience acquired at RMD in filling many thousands of packaged liquid powerplants and provides a margin for both the manufacturing tolerances that are inolved in the fabrication of the tankage and the tolerances encountered in the fill control procedure.

Two ports are provided in the design for filling the tank. The first of these is used for the initial fill and the second port provides the capability for draining and refilling. The drain and refill port is shown on Figure 5. The tank assembly is delivered with the mechanically sealed plug and welding plug installed. Prior to draining, the weld head on the welding plug is machined away using a hand tool, and the mechanical plug is removed. After draining and refilling a radially expanded Lee Plug (manufactured by the Lee Company, Westbrook, Connecticut) is installed, the mechanical plug re-installed as shown and a new seal weld is made. The fill port used for the initial tank fill is

Initial Hermetic Seal Closure



Hermetic Closure After Refill

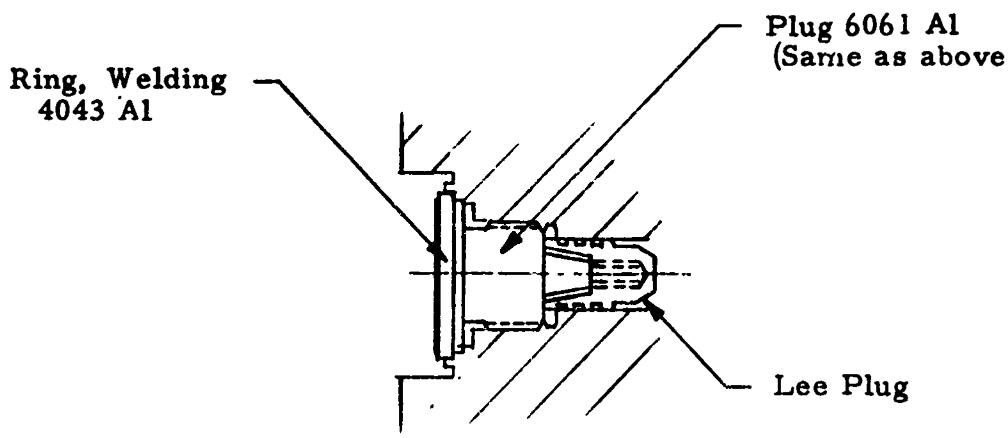


Figure 5. Drain and Refill Port Assembly

identical to the refill port installation.

The propellant outlet port, designed to accept an AN flared tube fitting, is equipped with a welded-in burst disc to hermetically seal the propellant storage. The disc is designed to burst at 150 psia to allow a margin above the maximum hydrostatic pressure (100 psi) resulting from the specified shock load plus vapor pressure.

The Rolldex expulsion system operates by the introduction of pressurizing gas behind the annular piston as shown on Figure 6, which shows the Rolldex in the storage, 50%, and 100% expelled positions. The force generated by the pressurizing gas moves the annular piston causing the outer diaphragm to turn outside-in and roll along the tank wall, and the inner diaphragm to turn inside-out and roll along the center support tube as depicted in Figure 6. When the piston "bottoms" at the end of the expulsion cycle, the outer diaphragm expands to the tank wall and the inner diaphragm buckles around its support tube expelling the propellant remaining in the annular spaces created during the rolling operation.

3. PERFORMANCE CHARACTERISTICS

The performance characteristics of the developed positive expulsion tank assembly are summarized below:

Characteristic	Requirement	Developed Unit
Tank Diameter (in)	30	30
Tank Length (in)	---	42.4
Total Propellant Capacity (lb)	1100	1100
Internal Volume of Tank Shell (in^3)	---	23
Expulsion Efficiency (%)	98 min	99.87
Volumetric Efficiency (%)	95 min	95.5
Rolling (Actuation) Pressure (psid)	10 max	9.0
Operating Pressure (psia)	400	400
Proof Pressure (psia)	1.33 x Oper.	532
Burst Pressure (psia)	1.25 x Proof	665

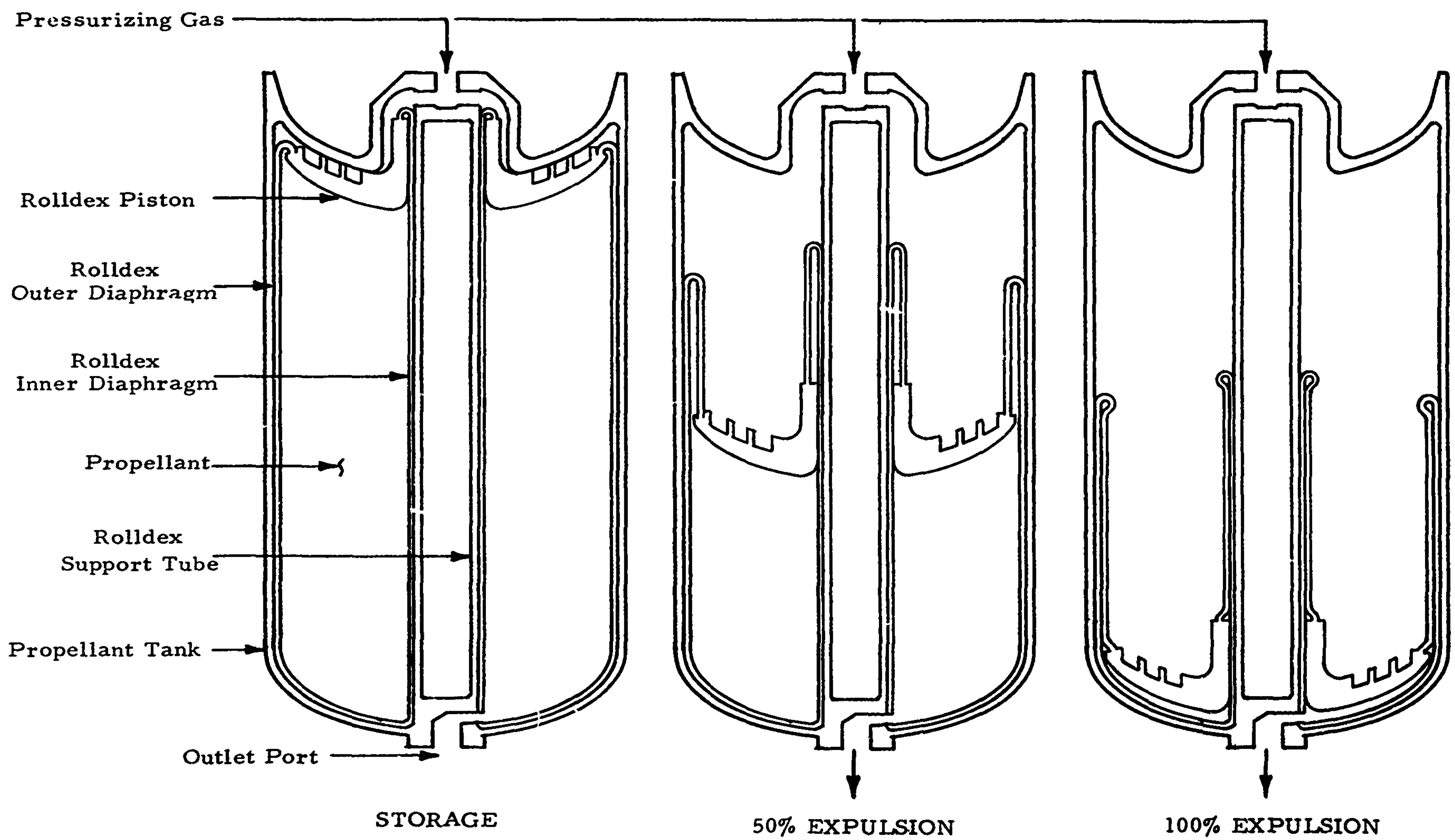


Figure 6. Metal Rolling Diaphragm Expulsion Sequence

a. Materials of Construction

The materials used in the fabrication of the developed design are summarized in Table I. All materials were selected for both their ease of fabrication and compatibility with the specified Nitrogen Tetroxide Propellant. In fact, one of the features of the developed assembly is that it provides a series of compatible N_2O_4 barriers, i.e, the aluminum Rolldex, Teflon bond, and maraging steel tank shell. A discussion of the specific factors leading to the selection of the various materials noted on Table I follows.

(1) Tankage

Eighteen (18) percent nickel (250 grade) maraging steel was selected as the most desirable tankage material, because of its ease of fabrication, excellent weldability, high weld efficiencies, simple heat treatment, excellent fracture toughness and ductility, and RMD experience with this alloy in this type of application. The design requirements which influenced the material selection included:

- Propellant Compatibility - Nitrogen Tetroxide
- Temperature +500F (external, operational)
+625F (in-process, fabrication)
- Pressure 400 psia (internal, operating)

(2) Rolldex Assembly

The pure aluminum and aluminum alloy family of materials was selected for the Rolldex assembly, again primarily because of ease of fabrication, excellent weldability and previous experience with these materials at Thiokol-RMD in similar Rolldex expulsion units.

The 1100-0 aluminum selected for the inner and outer diaphragms contains 99 percent aluminum with the remainder composed principally of iron and silicon with trace amounts of other elements. It was successfully employed by Thiokol-RMD on a number of similar expulsion systems. The 1100-0 aluminum has a yield strength of about 5000 psi and an ultimate strength between 11,000 psi (min) and 15,500 psi (max). It has an elongation of 20 percent in the intended thickness range, which for the proposed diaphragm provided the necessary ductility to sustain rolling and the subsequent expansion to the tank wall during final expulsion.

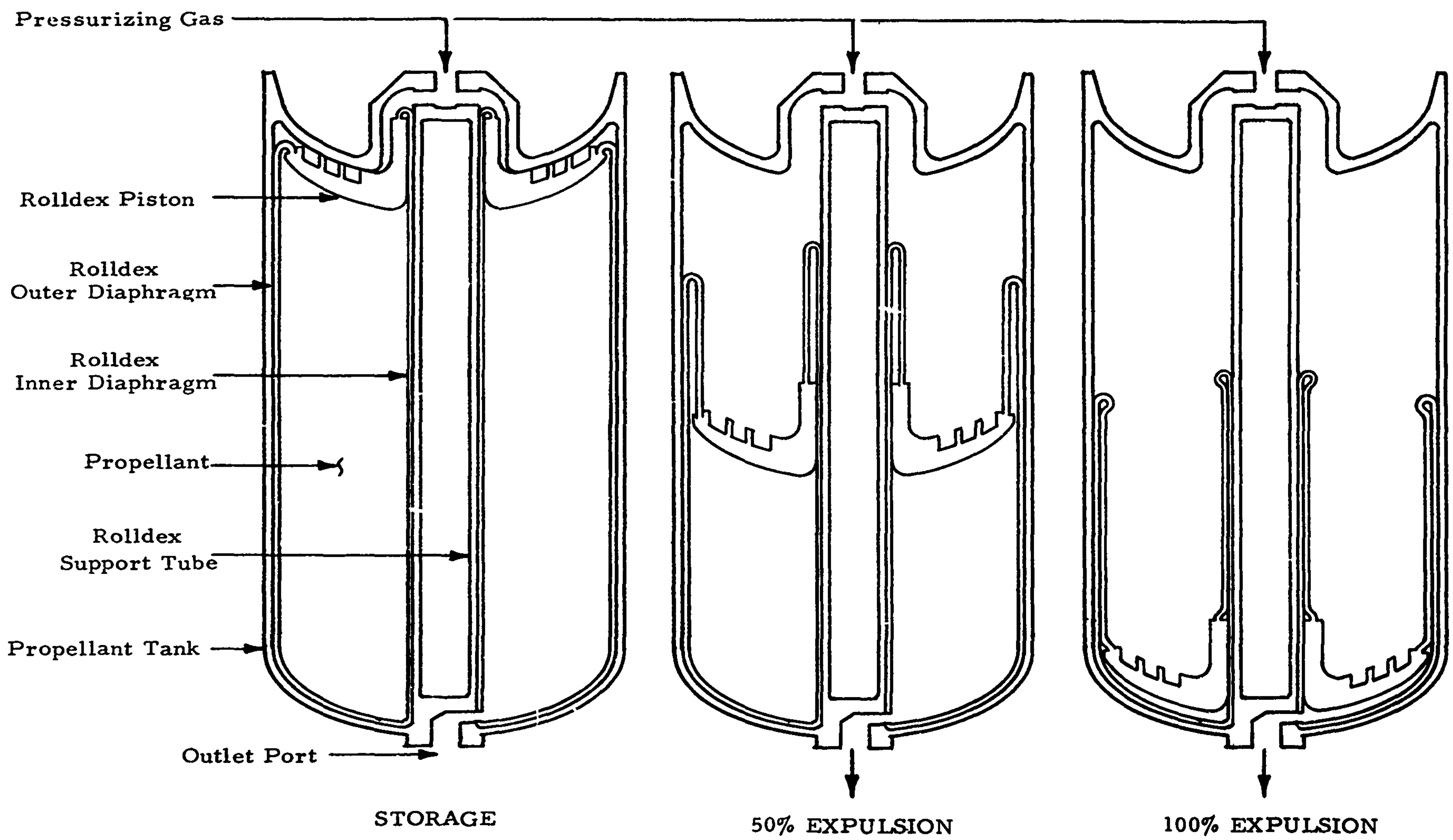


Figure 6. Metal Rolling Diaphragm Expulsion Sequence

The 6061-T6 aluminum alloy used in the piston is a moderate strength, corrosion-resistant and heat-treatable aluminum alloy. It is alloyed primarily with one percent magnesium, 0.6 percent silicon and 0.7 percent iron and contains minor amounts of copper and chromium. Minimum strength levels in the fully heat treated condition of 38,000 psi ultimate tensile strength, 35,000 psi yield strength and a percent elongation of 10, made the 6016-T6 an excellent choice for the piston.

A prime consideration in the selection of materials for the system was that they be suitable for long term storage in contact with nitrogen tetroxide (N_2O_4) and that they be suitable for operation after long storage periods. Both the 1100-0 and 6061-T6 base metals, are considered as Class I, suitable for long term storage of N_2O_4 according to DMIC Memorandum No. 201, "Compatibility of Materials with Rocket Propellants and Oxidizers." The foregoing data are confirmed by the Martin Company in their Fourth Progress Report, Me Report No. 76 on the "Compatibility of Materials in Storable Propellants for XSM-68 Band SM-68B." This latter report also indicates the satisfactory compatibility of weldments of the following aluminum alloys: 2014-T6, 6061-T6, 2219-T81, 5086-H34, H36, and 5456-H24, H321.

b. Structural Design Margins

The structural capabilities of the delivered tank assembly based on a detailed structural analysis are summarized in Table II. The minimum margins of safety noted are for the maximum temperatures which would exist under all operating conditions. Storage temperatures were specified as noted previously from -65F to +150F empty, and from 40F to +120F with the system loaded with propellant. Maximum operating temperatures were based on a computerized thermal analysis results of which are presented on Figure 7. The analysis was based on the following conditions:

. Gas Pressure	400 psia
. Pressurizing Gas Temperature	1000 F
. Initial Tank/Propellant Temp	120 F
. Propellant Flow Rate	4 lb/sec N_2O_4

The computerized analysis providing analytical expulsion predictions, consisted of a transient heat conduction simultaneous equation solution coupled with solutions for the expulsion of a fluid with a positive expulsion device driven by a compressible gas.

The critical structural design considerations were:

- Dynamic load capabilities versus the most severe conditions resulting from startup and operation.

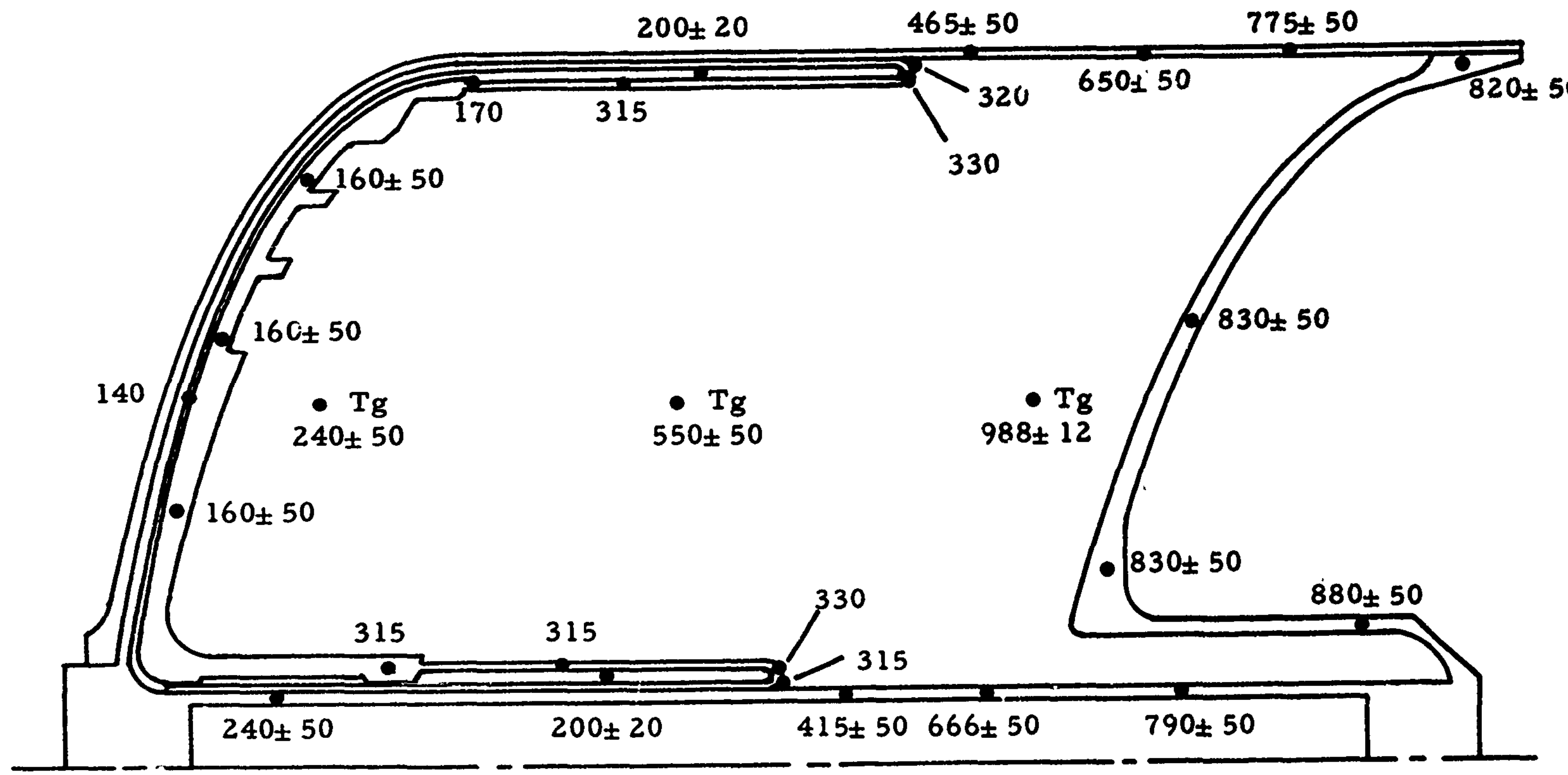
TABLE II

STRUCTURAL DESIGN MARGINS

Design Based On:

- ProofPressure of 1.33 x Working Pressure
- Burst Pressure of 1.66 x Working Pressure
- Materials Properties at Maximum Operating Temperature

Tankage Items	Condition	Temp °F	Min Margin of Safety %
Cylindrical Shell	Burst Pressure	830	97
	Buckling Pressure	Ambient	162
Upstream Closure Outer Joint	Proof Pressure	830	16
Upstream Spherical Head	Buckling (Burst Pressure)	830	99
Downstream Elliptical Head-Cylinder Junction	Burst Pressure	200	114
Downstream Elliptical Head-Center Opening	Burst Pressure	140	35
Rolldex Items			
Diaphragm Outer	Premature Stretch to Wall	380	78
Diaphragm Inner	Premature Buckling	350	856
Outer Rolldex - Piston Weld	Operating Load	170	80 on yield
Inner Rolldex- Piston Weld	Operating Load	350	33 on yield
Rolldex Elliptical Head	Buckling (Vacuum Filling)	Ambient	454
Piston	Dynamic Moment	120	133



30" Rolldex Tank
Maximum Temperatures °F

Figure 7. Maximum Rolldex/Tank Temperatures

- The pressure required to roll the Rolldex diaphragm versus the pressure which will expand the diaphragm to the wall.

- The stretch and load conditions during the bottoming out of the piston when the inner diaphragm buckles around its support tube and the outer diaphragm expands to the tank wall.

A dynamic load condition occurs during initial operation as the piston advances through the ullage and contacts the propellant. If the surface of the propellant is at an angle to the piston, cocking moments result, the severity of which is a function of both the liquid angle and the pressure differential across the Rolldex. These cocking moments are transmitted by the piston hub through the inner Rolldex diaphragm into the guide tube. To minimize these cocking moments, the piston hub dimensions of the design were established to give adequate bearing surface and to resist cocking moments, thereby, maintaining the loads on the inner diaphragm within allowable limits. Since no initial pressurizing rate or tankage attitude was specified, the tank design was analyzed for an initial pressure rise rate of 20 psi/sec and for tank attitudes over the bands of ±20° from both horizontal and vertical assembly in the missile. Under these conditions the design has the capability with a 133% margin of safety, to resist overturning moments during the starting or arming sequence. Overturning moments resulting from acceleration forces during operation (± 2g axial ± 1g transverse) were determined to be less than the loads developed during startup and thus also within the design structural capability.

The pressure to roll versus the pressure to stretch considerations concern the relationship of the pressure force required of the piston to roll the diaphragm, and the strength of the rolled over portions of the diaphragm to resist operating pressure differentials without stretching out to and buckling into the unrolled portions. In other words, the thickness of the diaphragm must be selected so that rolling will take place at a lower pressure differential than is required to expand the outer diaphragm, or cause buckling of the inner diaphragm. In selecting the material thickness, the operational temperatures at the rolling radius of the diaphragms must be taken into account. For buckling, account must be taken of the length of the rolled inner diaphragm which is most critical just before the piston bottoms at the tank head.

As noted on Table II, the margin of safety for premature stretch of the outer diaphragm is 78% and for premature buckling of the inner diaphragm, 856%.

Stretch and loading of the diaphragms during bottoming out of the piston is the final critical design consideration. At this point in the operation, the pressure differential across the diaphragm rises and it is desired that the outer diaphragm stretch to the tank wall and the inner diaphragm to the tank wall occurs provided sufficient elongation remains in the partially work hardened rolled cylinder. Laboratory tests conducted during the program, (See Section 4.0) showed a stretch capability of 26% versus the required 24%.

SECTION III

FABRICATION

The major steps in the fabrication of the positive expulsion tank assembly are depicted on Figure 8. The major subassemblies comprising the top assembly were:

- The maraging steel shell and head assembly consisting of the cylindrical shell and dome joined by a circumferential weld.
- The piston, dome and subassembly, and outer diaphragm assembly. Again welds were used to joint the various individual pieces.
- The inner diaphragm bonding assembly consisting of the inner diaphragm, its support tube assembly and the diaphragm support. The support is joined to the diaphragm by a weld.
- The closure assembly fabricated by welding two semifinished forgings (a dome section and a hub section) together and finish machining to the desired contour.

The final assembly was accomplished in steps by bonding the piston, dome and hub assembly, and outer diaphragm assembly to the steel shell and head assembly; installing the inner diaphragm bonding assembly and welding the inner diaphragm to the Rolldex piston hub; and finally installing and welding the maraging steel closure to the shell and head assembly at the inner support tube and outer shell as shown on the assembly flow diagram. Details regarding the specific fabrication techniques employed are discussed in the subsequent sections.

1. MARAGING STEEL SHELL ASSEMBLY

The 250 grade maraging steel shell assembly consisted of two pieces; a dome which was machined from a forged piece, and a shell which was fabricated from a 3/8 inch thick rolled and welded plate which was subsequently finished machined on the I. D. and O. D. to a 0. 10 inch wall thickness. The finished machined shell is shown on Figure 9 and the finished machined dome on Figure 10. The shell and dome were joined by a multipass DC Tungsten Arc Weld using 250 grade maraging steel filler wire. This same type of weld was employed for the longitudinal butt weld in the shell. Following welding of the dome to the shell the assembly was maraged in a furnace at 900F for 3 hours. The aging operation was followed by a hydrostatic proof pressure test which was in turn followed by the application of a protective coating to all exposed metal surfaces.

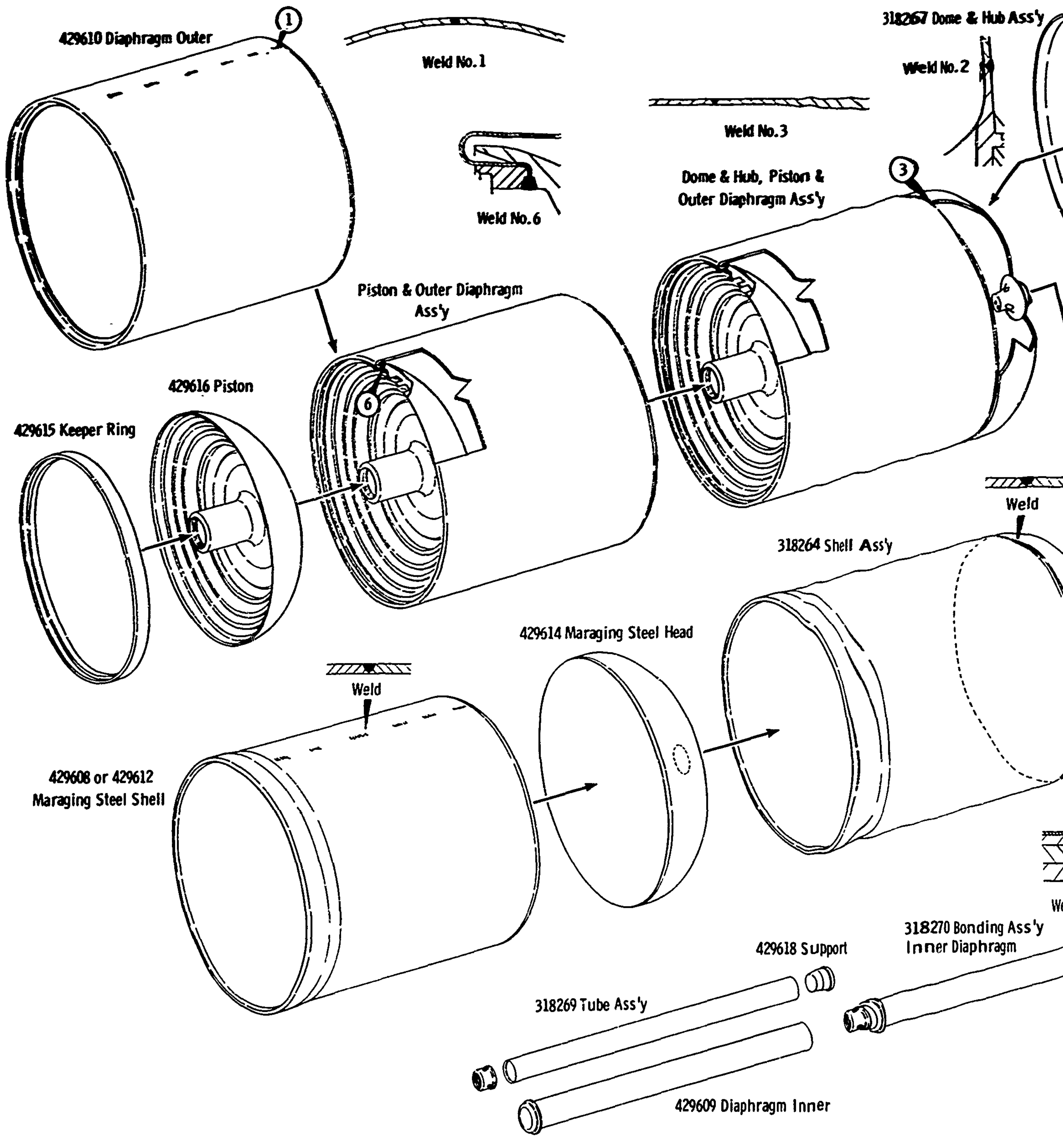
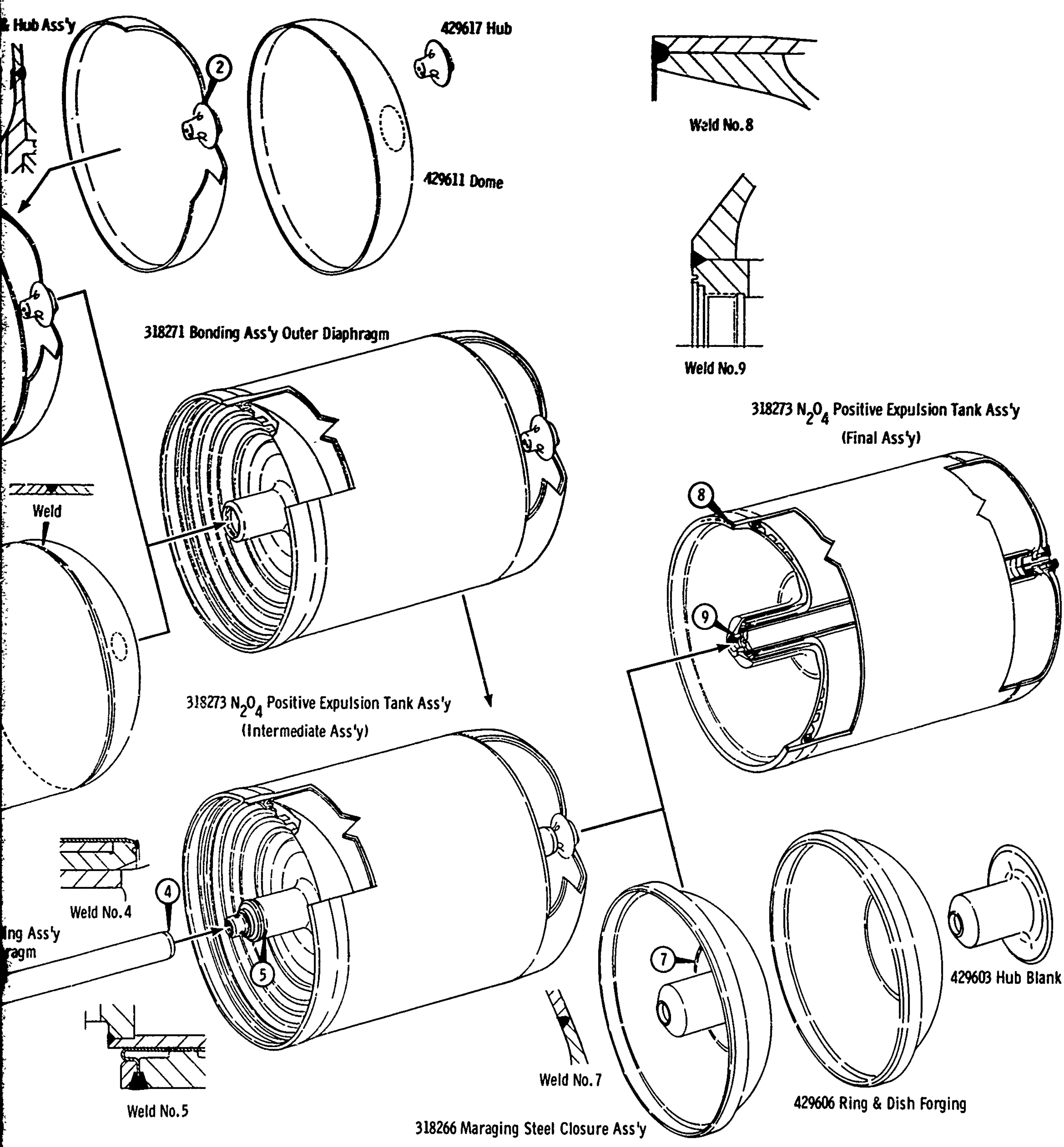


Figure 8. Positive Expulsion Tank Assembly Flow Sequence


Hub Ass'y
429617 Hub
429611 Dome
Weld No. 8
Weld No. 9
318271 Bonding Ass'y Outer Diaphragm
318273 N_2O_4 Positive Expulsion Tank Ass'y
(Final Ass'y)
Weld
318273 N_2O_4 Positive Expulsion Tank Ass'y
(Intermediate Ass'y)
Weld No. 4
ing Ass'y
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429603 Hub Blank
Weld No. 7
429606 Ring & Dish Forging
Weld No. 5
318266 Maraging Steel Closure Ass'y

B

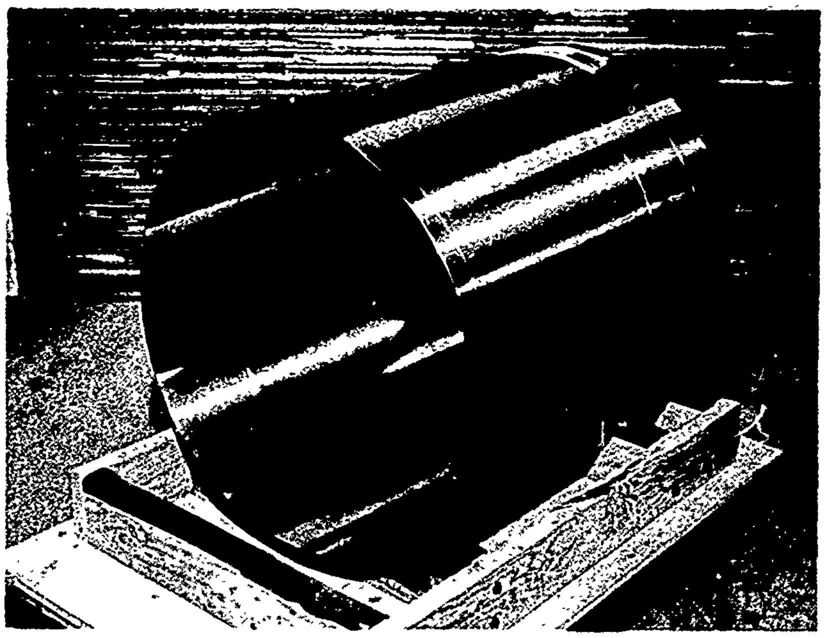

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Figure 9. 429612 Maraging Steel Tank Shell

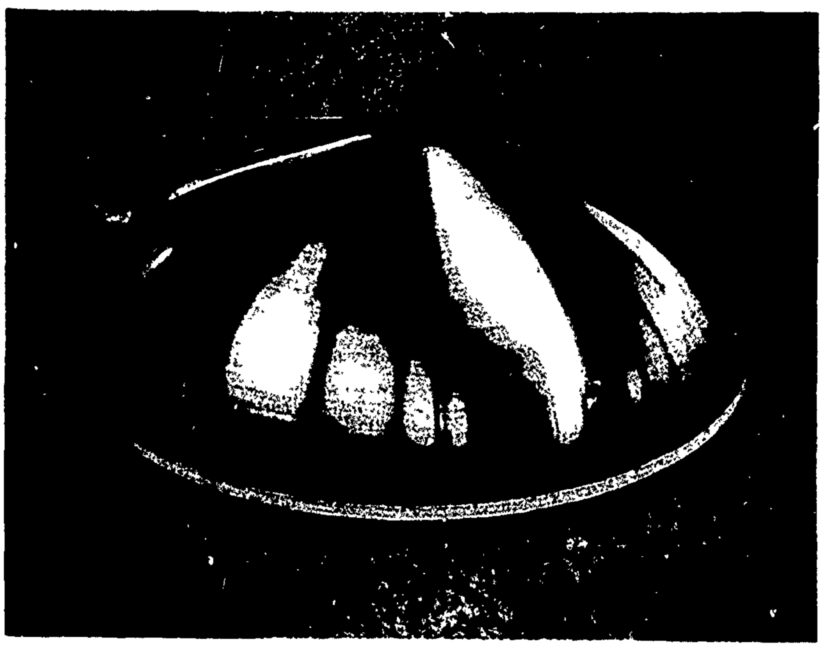

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Figure 10. 429614 Maraging Steel Tank Dome

Selection of the roll and welded approach for fabrication of the tank shell was made after consideration of other processes including roll extrusion, spinning, and drawing. Because of the limited number of tank assemblies required for the program, the rolled and welded construction was the most economical from the tooling standpoint. Selection of this method did, however, result in fabrication problems. It was initially planned to roll and weld the 3/8 inch thick sheet and finish machine to the 0.110/0.100 wall thickness without any intermediate anneals. However, problems were encountered in both "rounding" the roll and welded shell and in keeping the shell round during the subsequent machining operations. As a result of these problems, extensive tooling modifications were required to provide more positive "fixturing" of the shell during machining. In addition, an "in process" stress relief of the shell was added to relieve any stresses tending to distort the shell. These process modifications resulted in acceptable shell assemblies.

The finished machined maraging steel tank shell assembly was protectively coated on its O.D. and on the I.D. in areas where bonding to the Rolldex was not required with a corrosion resistance coating compound known as Sermetel W. This compound manufactured by Teleflex, Inc., North Wales, Pa., is a completely inorganic coating formula consisting of an aqueous inorganic binder solution with aluminum added as a filler. Thiokol-RMD had previously used this coating system for maraging steel tankage and it proved to be highly effective in the prevention of erosion, salt spray corrosion, and the corrosion which normally results from exposure to cyclic heat oxidation/salt spray environments. Sermetel W was applied to the tank after grit blasting by spray coating following which the coating was cured at a temperature of 650F. Thickness of the coating was 3 mils.

The completed Seremetel W coated tank shell assembly was then stocked and available for assembly to the outer diaphragm bonding assembly.

2. OUTER DIAPHRAGM BONDING ASSEMBLY

This assembly was comprised of the 6061-T6 Rolldex piston, the 1100-0 outer diaphragm and the 6061-T6 dome and hub assembly. The piston was machined from a forged aluminum billet since only six deliverable units were required. A die forging would normally be used for this component. Figure 11 shows two stages of the rough machining operations on the piston. The 1100-0 aluminum outer diaphragm (.040 inch thick) was fabricated from rolled and welded sheets. A DC Tungsten Arc single pass automatic machine weld was utilized. Filler wire was 1100 aluminum. Following welding the diaphragm was helium leak tested to a level of 1×10^{-8} scc/sec and the diaphragm was Teflon coated. It is significant to note that the longitudinal weld

in the outer diaphragm experiences severe service conditions in the Rolldex assembly, particularly during post-roll circumferential expansion of the outer diaphragm to the tank wall. In previous programs it was found that failures of this weld joint would occur if the weld was weaker and/or exhibited lower ductility than the parent material. On the basis of considerable tensile testing of such weldments, Thiokol-RMD determined that weldments must be made with sufficient weld crowns on both sides of the sheet to permit a final "dressed" weld bead reinforcement of "flush" to +0. 003" on the diaphragm O. D. and +0. 003 to +0. 005" on the I. D. These weld dimensions did not interfere with bonding of the O. D. to the tank wall or with the rolling action of the diaphragm, and most important, were satisfactory with respect to weld strength and ductility.

The next operation in the forming of the outer diaphragm bonding assembly was the welding of the outer diaphragm to the piston. This weld joint shown on Figure 12 actually joins three pieces, the 6061-T6 piston, 1100-0 outer diaphragm, and 6061-T6 keeper ring which supports the Rolldex in storage against vapor pressure loads and prevents bending loads on the weld during the rolling operation. A two pass manual AC Tungsten arc weld with 4043 filler wire was utilized to complete this weld.

The final subassembly operations in the fabrication of the outer diaphragm bonding assembly were the fabrication of the dome and hub assembly and the welding of this subassembly to the piston and outer diaphragm subassembly. The 6061-T6 dome was purchased as a spun piece and the 6061-T6 hub was machined from bar stock. The hub to dome manual weld (AC Tungsten Arc with 4043 filler wire) was then accomplished and the completed joint helium leak tested to a level of 1×10^{-8} scc/sec. Some difficulty was experienced in making the dome to hub weld due to a changing radial gab as the circular butt weld was made. These difficulties were resolved by modifying the weld chill ring and redesigning the weld fixture to provide a more positive restraint of the parts. Figure 13 shows the completed dome and hub assembly.

The final welding operation on the outer diaphragm bonding assembly was the welding of the dome and hub assembly to the outer diaphragm. The weld was accomplished as a single pass automatic DC Tungsten arc weld using 4043 filler wire. Again a helium leak test of the finished weld was conducted.

One of the unique features of this weld was the method of removal of the copper weld chill used to back up the weld. Since the piston was in place when this weld was accomplished successfully on all fabricated assemblies by mounting the assembly in a vertical position and loading the assembly with nitric acid to a level just above the chill ring. The entire "etching out" operation required approximately one hour. The helium leak test of the weld joint was

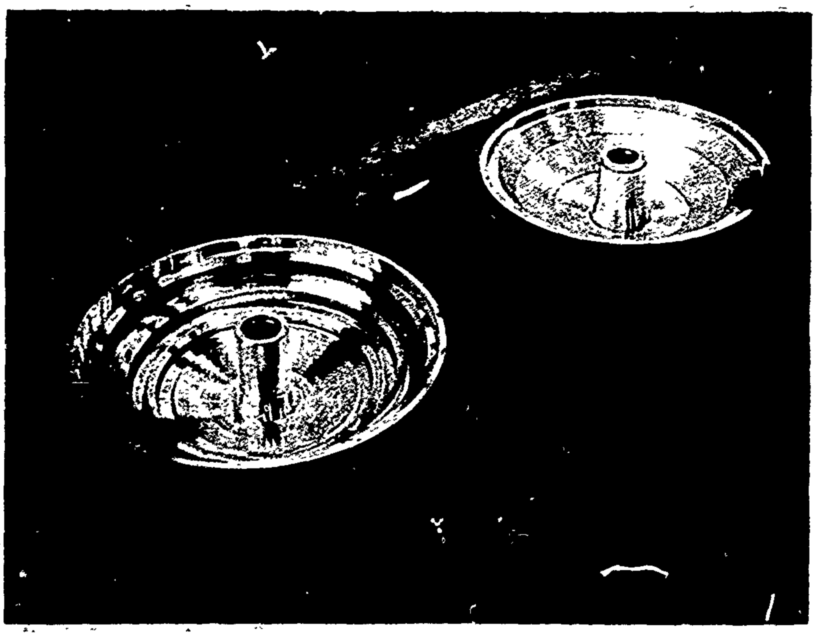

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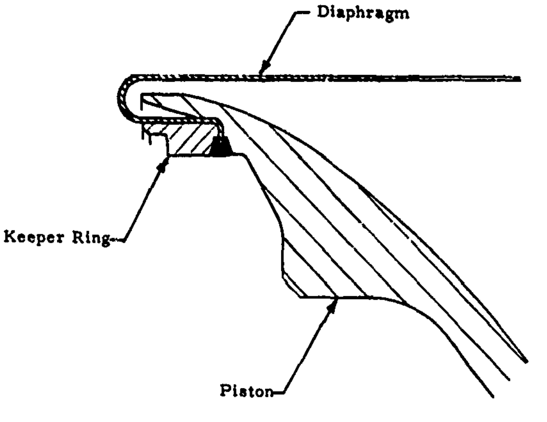
Figure 11. Rough Machined Rolldex Piston



Type Weld:	AC Tungsten Arc
Base Metal:	1100-0 Aluminum Diaphragm to 6061-T6 Aluminum Piston
Electrode or Filler:	Root Pass - ER 4043 Complete Weld - ER 4043

Figure 12. Outer Diaphragm-to-Piston Weld Joint

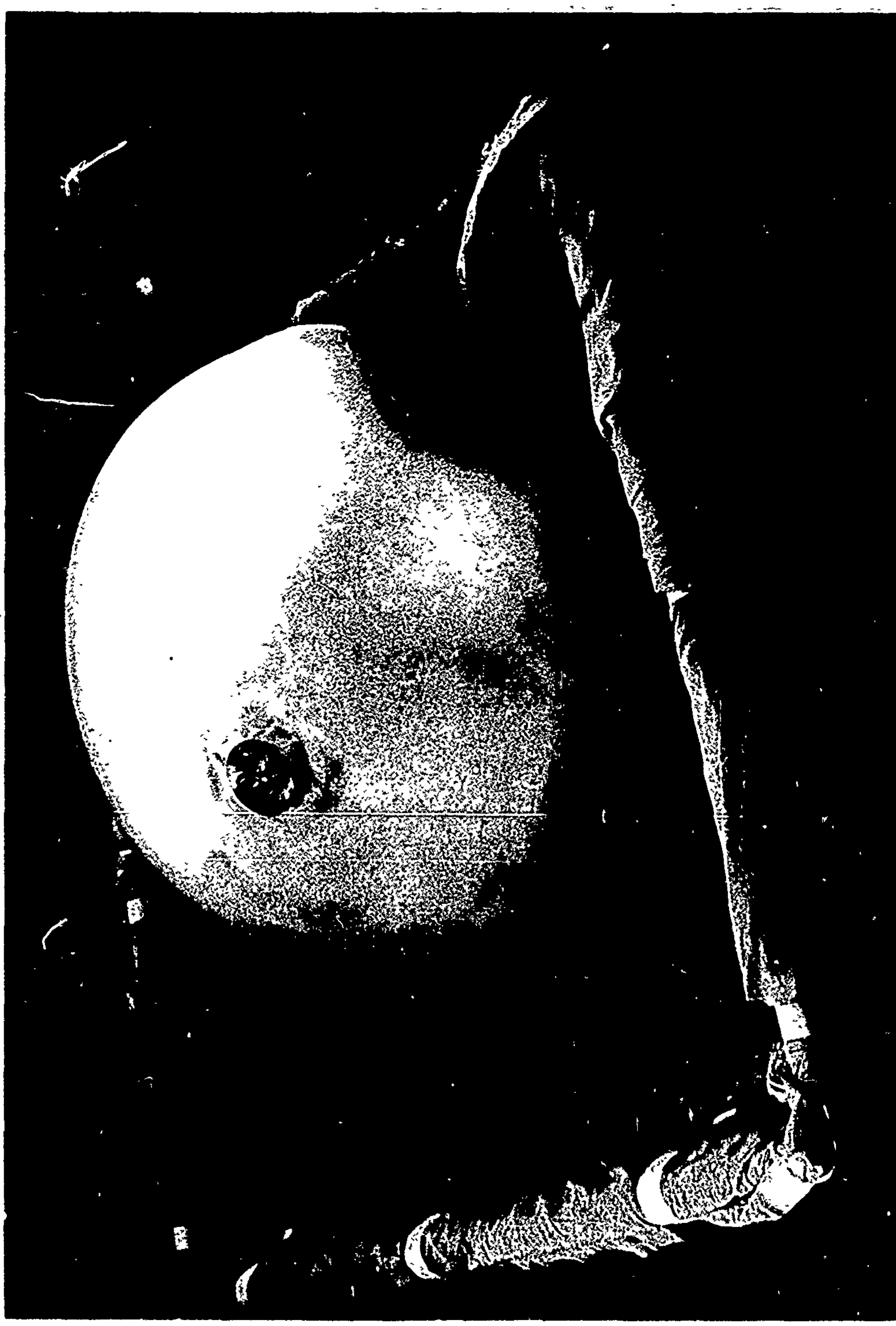


Figure 13. Dome and Hub Assembly

(9108-33)

repeated after the etching operation. Figures 14 and 15 show the welding fixture for outer diaphragm to piston and outer diaphragm to dome welds and Figure 16 the completed hub, dome, piston and outer diaphragm assembly.

The final operation was the bonding of the outer diaphragm assembly to the maraging steel shell and head assembly. This operation was accomplished by inserting the outer diaphragm assembly inside the shell, installing a fixture and pressurizing the Rolldex diaphragm against the tank wall. To prevent air entrapment between the tank wall and Teflon coated diaphragm the bond line was evacuated prior to pressurization. Following pressurization the unit was placed in a heat treat furnace capable of raising the unit temperature to the melting point of Teflon and the bonding operation completed.

3. INNER DIAPHRAGM BONDING ASSEMBLY

This assembly was comprised of the 1100-0 aluminum inner diaphragm, the CRES 347 diaphragm support tube assembly, and a 6061-T6 diaphragm support. The inner diaphragm, Figure 17 was purchased as a spinning. The diaphragm support tube was machined from tubing and Teflon coated. The diaphragm was then assembled to the support tube in a fixture which permitted pressurization of the diaphragm O. D., and bonded in a heat treat furnace capable of heating the assembly to the melting point of Teflon. Following this operation, the diaphragm was welded to its end support completing the subassembly. A manual AC Tungsten arc fusion weld using 4043 filler wire was used following which the weld was helium leak tested to a level of 1×10^{-8} scc/sec to determine its storability integrity.

4. FINAL ASSEMBLY

Final assembly was accomplished as follows:

- Assembly, welding and leak testing of inner diaphragm bonding assembly
- Assembly, welding and leak testing of maraging steel closure
- Finalization and painting of deliverable units.

The first step of the final assembly is accomplished by inserting the inner diaphragm bonding assembly through the piston until the tapered diaphragm support engages the hub and the flanged end of the inner diaphragm engages the piston. A keeper ring smaller but similar to the outer diaphragm

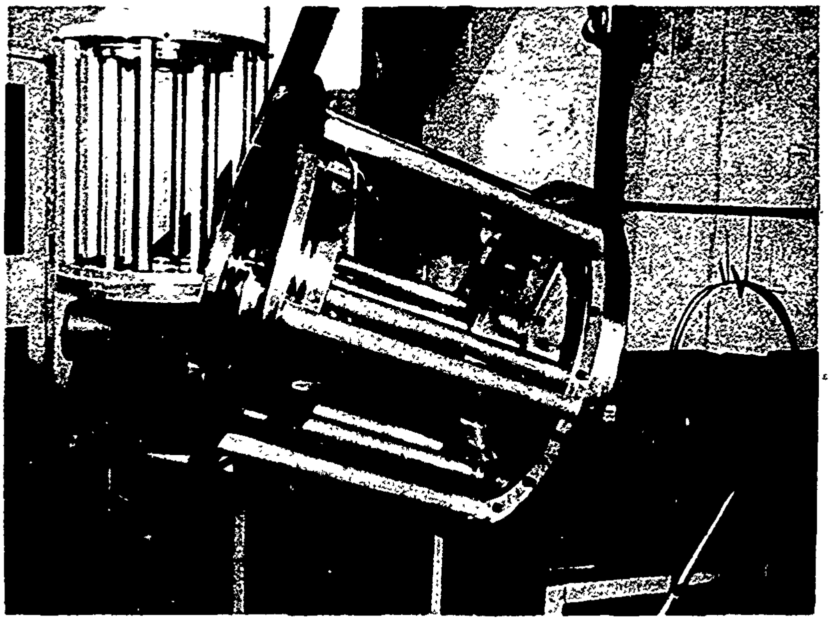


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Figure 14. Welding Fixture - Weld Piston to Outer Diaphragm

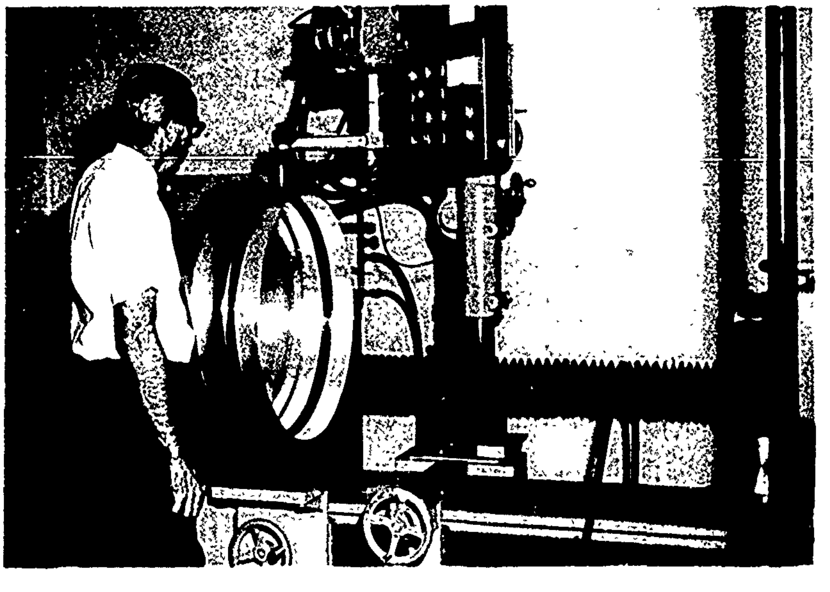

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Figure 15. Welding Fixture and Weld Sample - Weld Outer Diaphragm to Rolldex Aft Dome

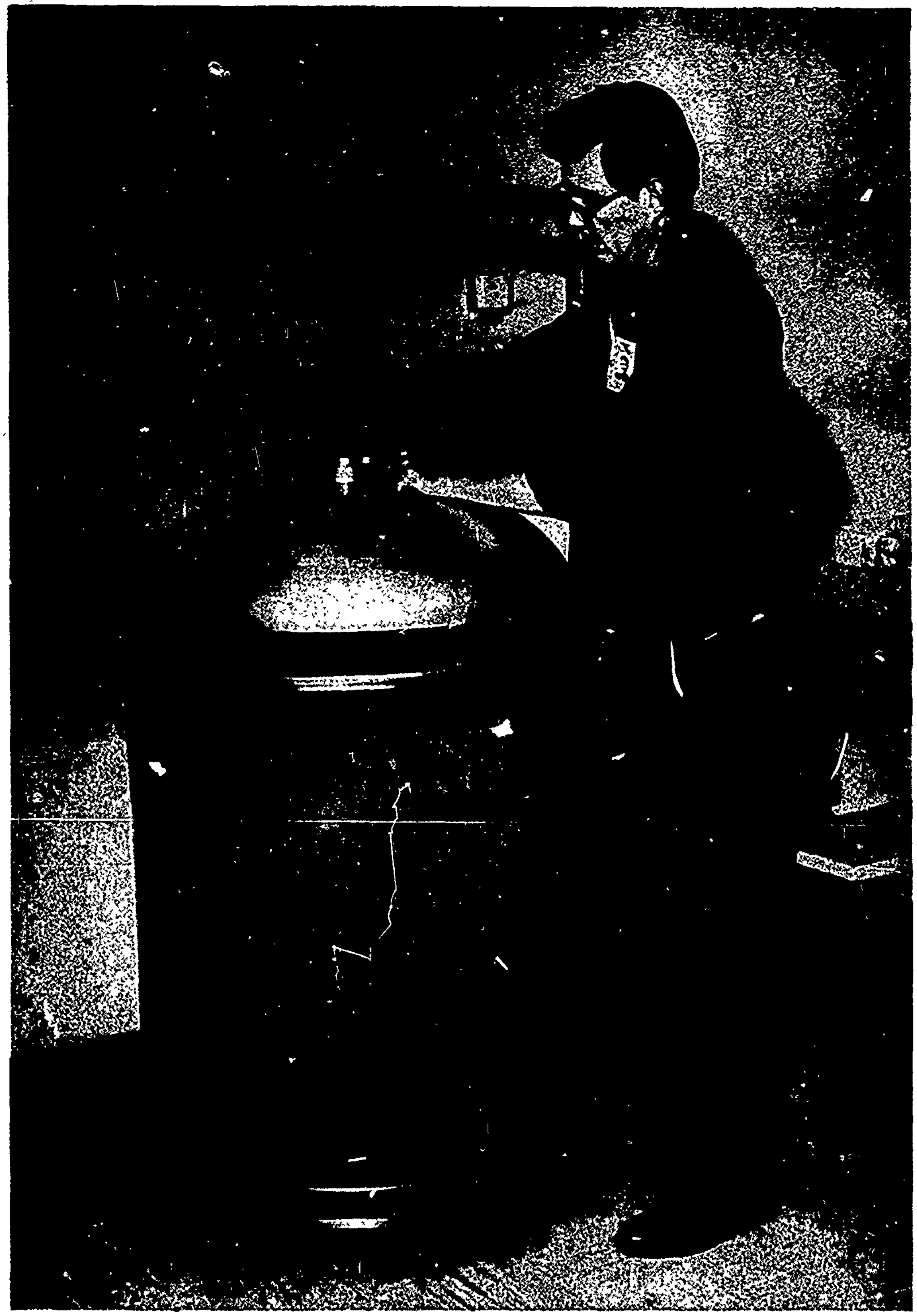

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Figure 16. Hub, Dome, Piston and Diaphragm Assembly

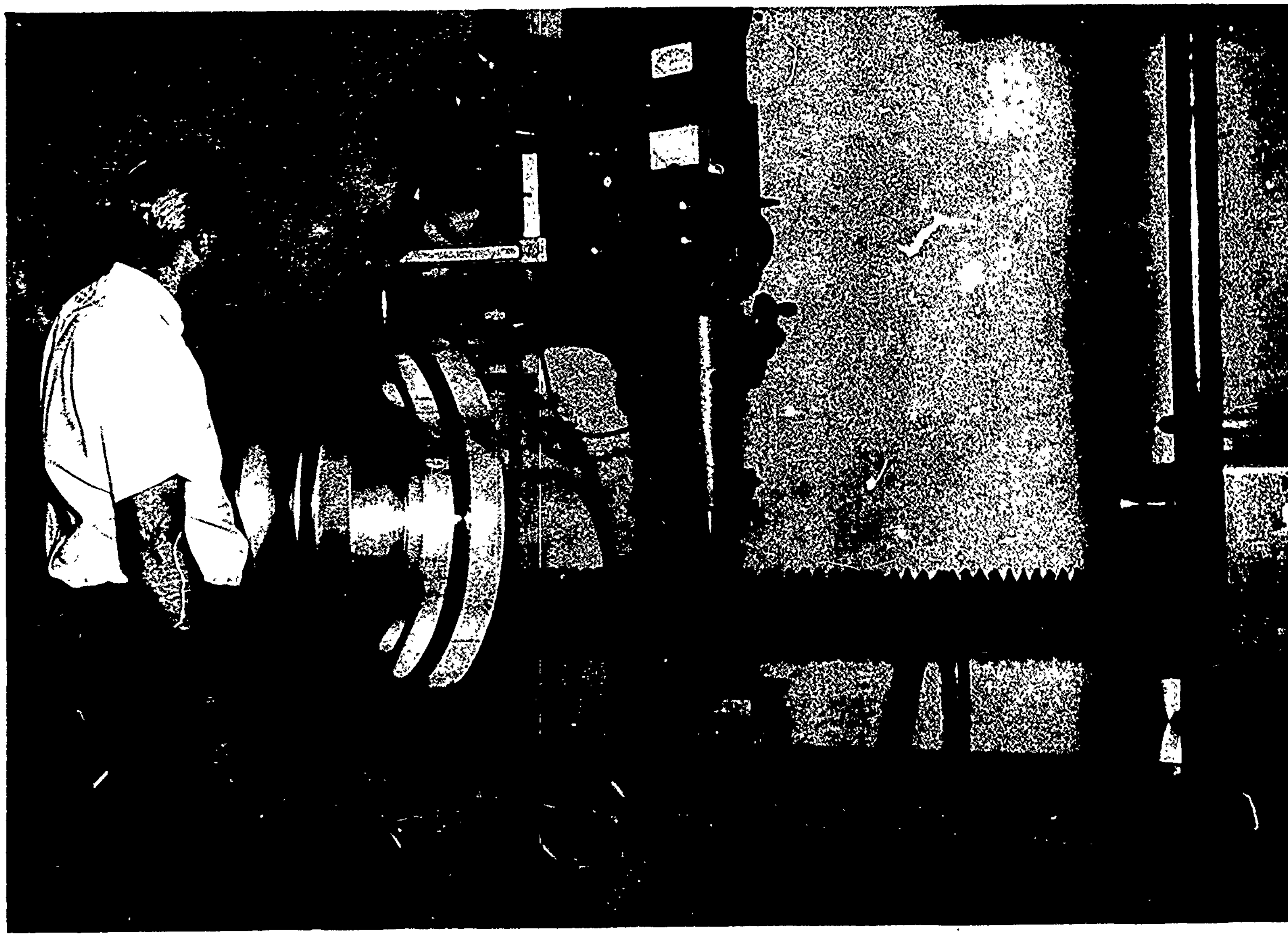

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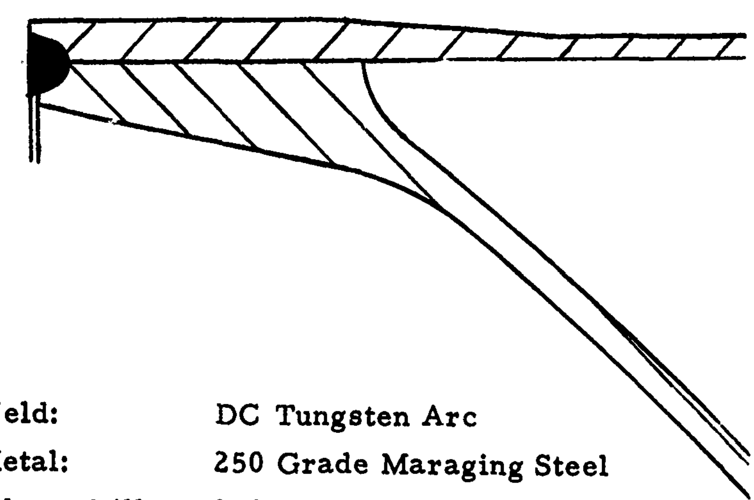
Figure 17. Inner Diaphragm

keeper ring is installed and a three component weld which joins the 6061-T6 keeper ring, 1100-0 diaphragm and 6061-T6 piston is made. As was the case with the outer diaphragm to piston weld, a two-pass manual AC Tungsten arc weld using 4043 filler wire is utilized.

Following completion of the weld, final helium leak tests to a level of 1×10^{-8} scc/sec are conducted. Both inner and outer diaphragm to piston welds are checked and the second of the final assembly steps is accommmplished. In this step the previously fabricated maraging steel closure is welded at its O.D. to the tank shell and at its I.D. to the CRES 347 inner diaphragm support tube. It is interesting to note that the final closure weld of the closure to the tank shell is made with the two maraging steel components in the fully-heat treated (maraged) condition. This double J groove joint (Figure 18) was accomplished by a multipass automatic machine weld using 250 grade maraging steel weld wire. The "as welded" final closure joint was necessitated by the fact that the aluminum Rolldex assembly could not be subjected to the 900F marage heat treat cycle without failure. Tests of 250 grade maraging steel weldments made in the fully heat treated condition with no subsequent heat treatment showed weld joint efficiencies greater than 70% of that of fully heat treated joints. Following completion of the welding operations, the welds were again helium leak checked and the final assembly operations undertaken.

Finalization of the assembly consisted of installing and seal welding an outlet fitting containing a 150 psi burst disc; seal welding a propellant drain and refill port, previously described in Section II; helium leak checking these two ports by introducing helium through a third port, the propellant fill port; and finally, painting of the deliverable assembly. Figure 1 provides an overall view of the completed tank assembly.



Type Weld: DC Tungsten Arc

Base Metal: 250 Grade Maraging Steel

Electrode or Filler: 250 Grade Maraging Steel

Figure 18. Tank Closure-to-Shell Weld Joint

SECTION IV

TEST RESULTS

The technical approach followed in the development of the N_2O_4 positive expulsion tank assembly was to integrate available technology with the program development effort. As such the program test effort was limited to the conduct of only those tests necessary to verify the design and demonstrate that the fabricated deliverable units would meet the specified design requirements. Three basic types of tests were conducted in the course of the development program to satisfy the above. These tests were:

- Mechanical Roll Tests - of the inner and outer diaphragm to verify rolling force, roll radius, inner diaphragm bonding parameters and outer diaphragm stretch capability.

- Helium Leak Tests - of all welded joints to verify long term storability characteristics.

- Demonstration Test - a single hot gas expulsion test to demonstrate the design under simulated operational conditions.

1. MECHANICAL ROLL TESTS

Two mechanical roll tests of an outer diaphragm and one mechanical roll test of an inner diaphragm were conducted. Results of the tests on the 1100-0 aluminum, 0.040 inch thick, 30 inch diameter, 14 inch long outer diaphragm are given below.

OUTER DIAPHRAGM MECHANICAL ROLL TEST RESULTS

	Test No. 1	Test No. 2
Rolling Force - lb	2400	2380
Roll Radius - in.	0.200	0.197
Total Elongation (%) at Fracture		
2 in. gage transverse	26	28
8 in. gage transverse	26	23

NOTE: Roll Rate 7.5 in/min.

The mechanical roll test was accomplished as shown on Figure 19 in a materials laboratory tensile load machine. The transverse (circumferential) elongation samples were taken from the rolled portion of the diaphragm and the elongation values represent the stretch capability of the rolled diaphragm, i.e., the capability of the diaphragm to expand to the tank wall. Based on the measured 0.2 inch roll radius the stretch required of the outer diaphragm is 2.4 percent. Thus the mechanical roll test demonstrated a more than adequate stretch capability. Figures 20 and 21 show outer

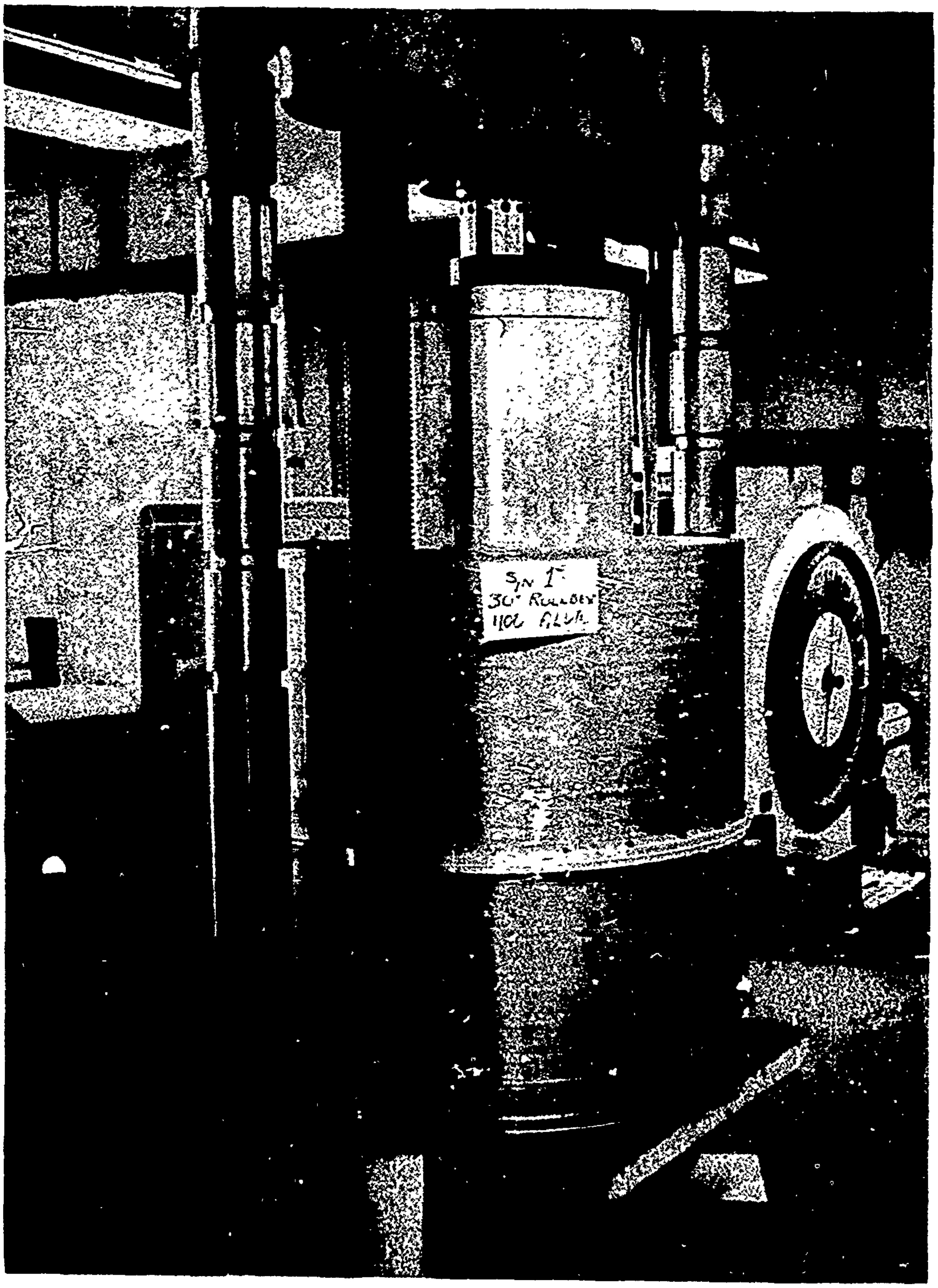


Figure 19. Outer Diaphragm Mechanical Roll Test Setup (9108-12)

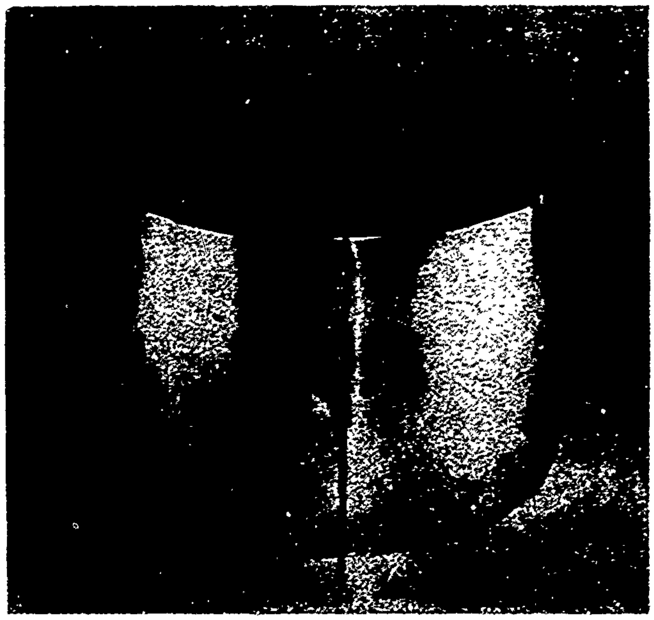


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Figure 20. 30-Inch Diameter Outer Diaphragm Before Rolling

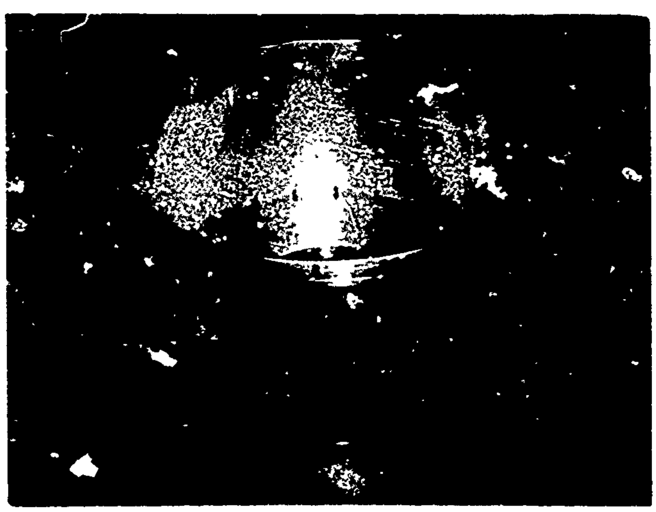

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Figure 21. 30-Inch Diameter Outer Diaphragm After Rolling

diaphragm before and after rolling. Visible in the diaphragm photo after rolling is a diamond pattern which is a result of work hardening the diaphragm during the rolling operation.

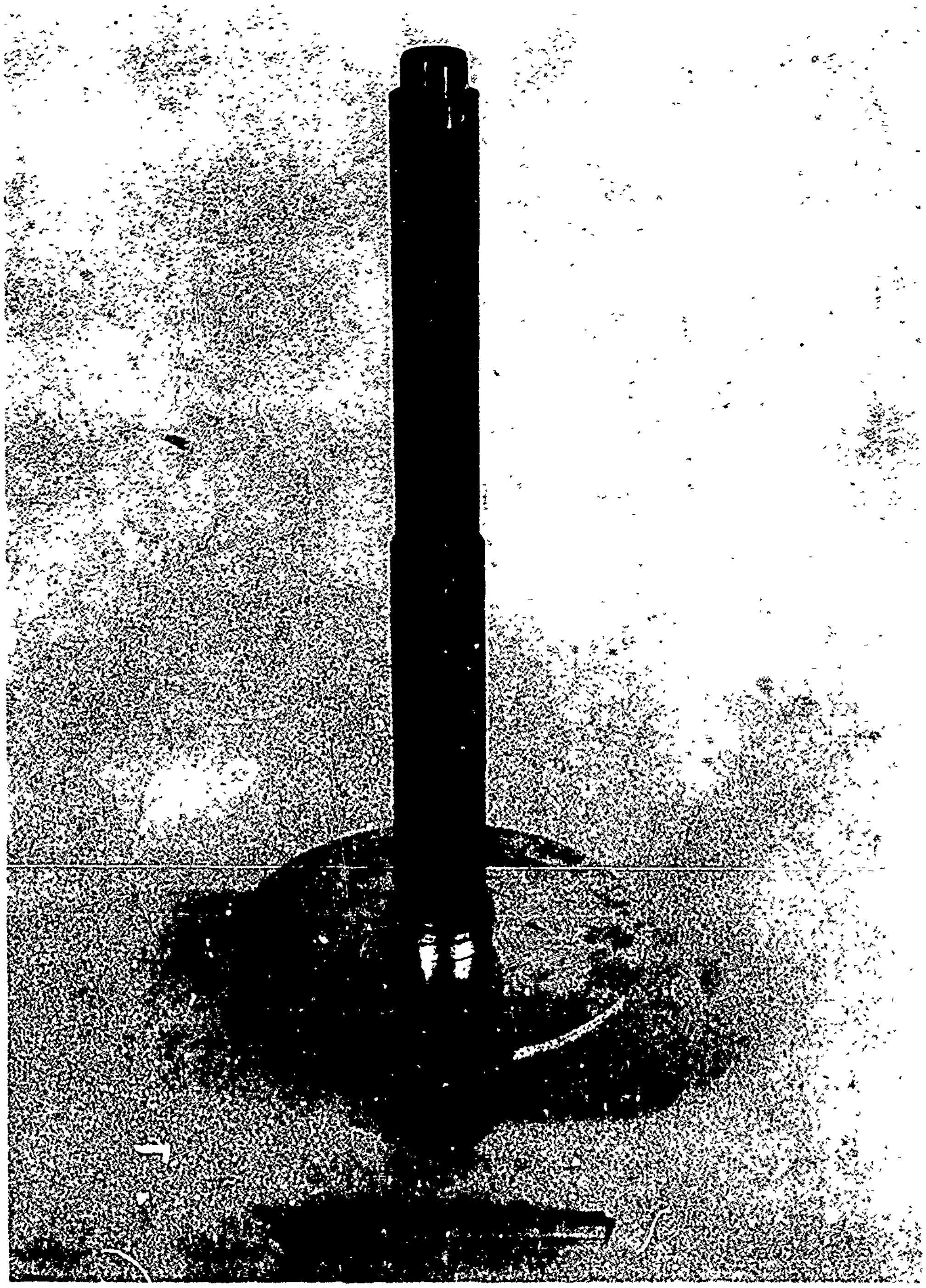
The mechanical roll test of the outer diaphragm was conducted both to check out bond tooling and bond parameters, and to verify rolling force. Results of tests showed adequate diaphragm to support tube bonds were obtained (bond failure was cohesive). Figure 22 shows the rolled inner diaphragm after the test. Results of the roll radius, roll force measurements were as follows:

Roll Force	945 lb
Roll Radius	.084 in

On the basis of the above mechanical roll test data, a rolling pressure was predicted for the design. In calculating the rolling pressure, the force required to peel the outer diaphragm bond was added to the outer diaphragm roll force since the mechanical roll test had been conducted with an unbonded outer diaphragm. A value of 10 lb/in was used for this force based on previous data available at Thiokol-RMD. On this basis, including an allowance for piston friction, a rolling pressure of 8 psid was predicted for the design. This value compared very well with the measured value of 9 psid during the demonstration (hot gas-expulsion) test.

2. HELIUM LEAK TESTS

At the beginning of the development program, it was recognized that in order to achieve a reliable, maintenance-free prepackaged liquid tankage system capable of long term storage with the specified "zero" liquid leakage, standard leak detection methods would not be sufficient. It was concluded that mass spectrometer helium leak detection techniques having maximum sensitivity (vacuum chamber method) would be required as a final inspection of all weld joints. Also recognized was the difficulty in specifying the finite value of helium leakage for mass spectrometer helium leak detection technique, i.e., that helium leakage rate for a particular leakage path below which it is certain that there will be no liquid leakage. When the helium leakage rate is extremely small, whether liquid leakage will occur and the amount of such leakage if it does occur, is dependent on the liquid properties, leakage path geometry, interfacial tension between the liquid and the barrier material, surface absorption effects, and laminar boundary layer effects. Investigations in this area have been carried out by Thiokol-RMD on the Surveyor Vernier engine program (1), General Electric Company (2), JPL (3), and Martin-Denver (4), with strong indications that true zero liquid leakage occurs as the



(6059-4)

Figure 22. Inner Diaphragm Bonding Assembly After Mechanical Roll Test

helium leakage rate approaches 10^{-8} cc/sec. Dr. William Marr of General Electric states that this occurs somewhere in the 10^{-5} to 10^{-8} cc/sec range. Weiner [5] defines zero liquid leakage as "that value of liquid leak or flowrate at which the surface tension of the liquid has just overcome the pressure acting on the liquid and no flow occurs." Weiner provides correlated liquid and gas flow data which also indicates that true zero liquid leakage occurs as the helium leakage rate approaches the 10^{-6} to 10^{-7} cc/sec range. Dr. Marr [6] notes that "most leaks in welds, brazes, and other joints tend to be relatively large. The only case where small (less than 10^{-7} atm cc/sec) leaks are encountered is in parts that receive special clean room treatment during manufacture. This is partly due to the clogging of leaks by water vapor and liquids which may be present."

On the basis of the above data it was concluded that a weld joint which leaked less than 1×10^{-8} scc/sec of pure helium under vacuum chamber test conditions would assure a zero liquid propellant leakage system. Accordingly, all weld joints in contact with propellant in storage were helium leak tested to a level of 1×10^{-8} scc/sec. In addition, the two maraging steel tank closure welds which were subject to vacuum conditions in storage were also helium leak tested. In the case of these two welds, however, different leakage criteria was established since the tank closure welds would seal the vacuum on the gas side of the piston during storage. Thus the concern was leakage of atmospheric air into the vacuum cavity and the development of a pressure differential across the piston of a magnitude sufficient to roll the piston. The vapor pressure of N_2O_4 on the liquid side of the Rolldex piston during storage at the minimum (40f) storage temperature is 6 psi. Based on the calculated 8 psid pressure to move the Rolldex piston, the pressure in the gas cavity of the Rolldex piston would have to reach 14.5 psi to move the Rolldex piston.

The attached curve, Figure 23 shows the estimated pressure rise after five years storage due to air leakage into the 110 in.^{3} void space in the 30 inch Rolldex expulsion system. These estimates assume that the measured helium leakage is due to pinholes and do not consider any diffusion effects. The calculations were made based on the following assumptions:

a. Ideal gas behavior
b. Pinhole flow represented by isentropic flow through a sonic orifice
c. The temperature in the void space remains constant as the pressure increases (i.e., isothermal process).

The above assumptions are considered conservative since either viscous or molecular flow conditions would yield considerably lower pressures in the gas cavity. In any event, it will be noted that a leakage rate in excess of

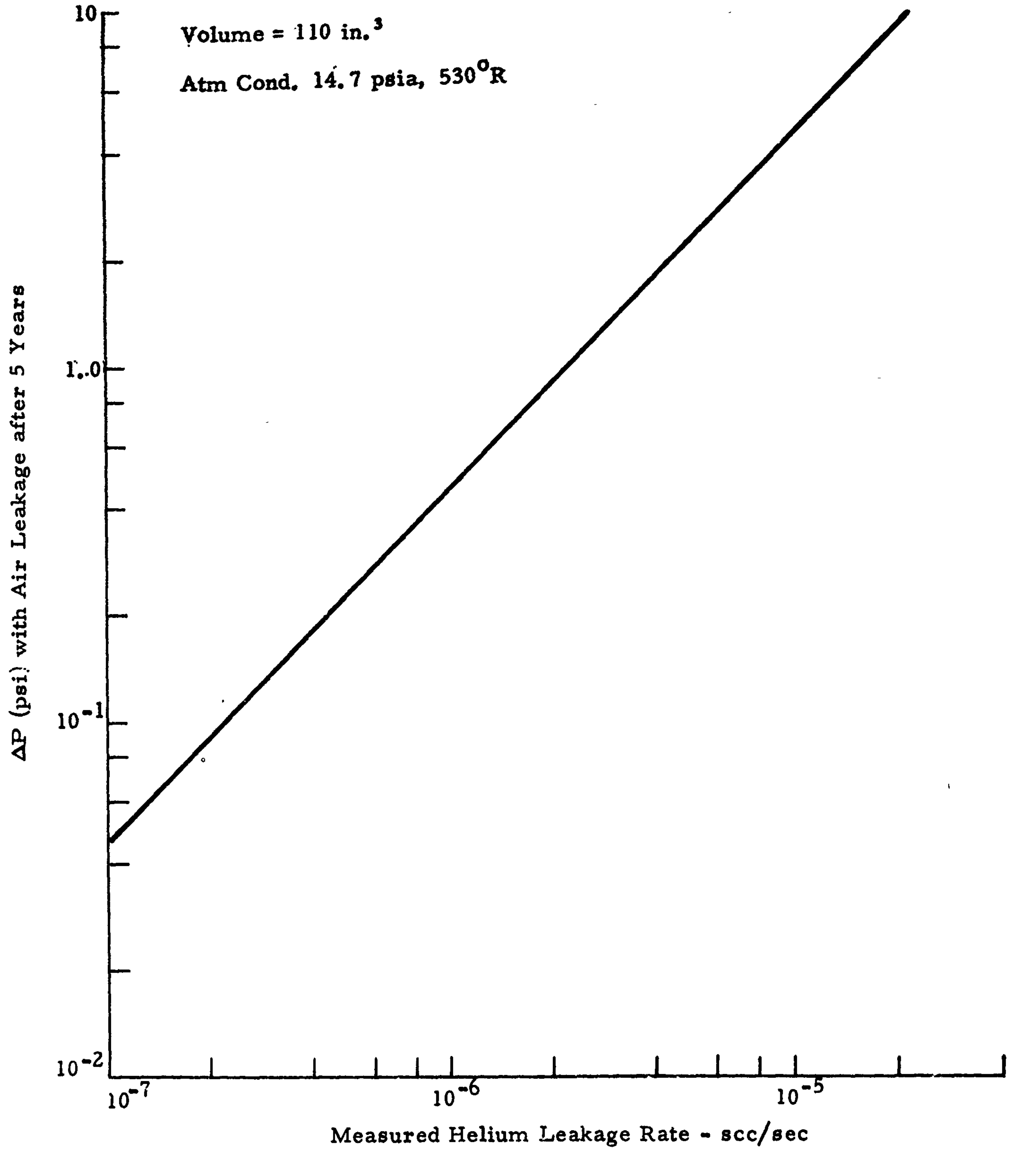


Figure 23. Estimated Gas Cavity Pressure Rise

1 x 10^{-5} cc/sec of helium would be required for the gas cavity pressure to reach a level in excess of 5 psi versus the 14 psi necessary to move the Rolldex piston at the minimum (worst case) temperature condition. On this basis a leak test to a level of 1 x 10^{-5} cc/sec was established for the two closure welds.

The specific technique employed for all leak tests was to introduce helium on one side of the weld being checked and to pull a vacuum on the other side. All leak tests were performed using a Consolidated Electrodynamics Corporation (CEC) mass spectrometer leak detector, Model 120A or 120B. Oil free helium gas with a purity of 99.99 percent or greater was used for all tests. Prior to the conduct of each leak test the equipment was calibrated using a standard helium leak rate. Figure 24 shows the setup for the Rolldex outer diaphragm leak test.

Results of the leak tests conducted on the first three deliverable units are summarized in Table III. The leak test results were extremely encouraging particularly when one considers that the nine weld joints represent approximately forty linear feet of weld. No attempts were made to pinpoint or locate the 10^{-7} or 10^{-8} level leaks. In the case of the two outer diaphragm to piston weld leaks, however, the probe technique was utilized in an attempt to locate the leak. This technique consisted of pressurizing one side of the weld with helium and very slowly moving a probe, equipped with a small rubber boot on the end, around the weld. With this technique it is possible to detect leaks in the order of 1 x 10^{-7} scc/sec. Attempts to pinpoint the outer diaphragm to piston weld leaks using the probe technique on the S/N 03 and S/N 04 units were unsuccessful. It was therefore concluded that the total leak rate shown on Table III was comprised of a series of small leaks (less than 1 x 10^{-7}) which would not result in liquid leakage, and the units were accepted for storage.

3. DEMONSTRATION TESTS

The culmination of the development effort on the program was the conduct of a demonstration test in which the positive expulsion tank assembly was loaded with water and the water expelled using the hot gas output of a hydrazine monopropellant gas generator.

The object of the test was to demonstrate successful operation of a positive expulsion Rolldex system of this size and to obtain data relating to rolling pressure and expulsion efficiency of the system. These objectives were successfully accomplished.

The method of test consisted of vacuum loading the positive expulsion portion of the tankage with water and applying hot gas (decomposed N_2H_4) to the gas side of the piston. Water expulsion was accomplished at approximately 370 psia and the run duration was approximately 300 seconds. N_2H_4 decomposition was accomplished with a gas generator of the thermal bed type.

TABLE III

HELIUM LEAK TEST SUMMARY

Joint No.	Weld Joint	Measured Helium Leakage Scc/Sec S/N 02	S/N 03	S/N 04
1	Outer Diaphragm Longitudinal Butt	$<3.6 \times 10^{-10}$	$<2.5 \times 10^{-10}$	$<1.2 \times 10^{-9}$
2	Outer Diaphragm Dome-to-Hub	$<2 \times 10^{-10}$	$<2.8 \times 10^{-10}$	$<2.8 \times 10^{-10}$
3	Outer Diaphragm to Dome & Hub Assy	$<3.3 \times 10^{-10}$	$<3.8 \times 10^{-10}$	$<5.4 \times 10^{-8}$
4	Inner Diaphragm to Support	$<3.1 \times 10^{-10}$	$<2.7 \times 10^{-10}$	$<3 \times 10^{-10}$
5	Inner Diaphragm to Piston	2×10^{-7}	$<2.7 \times 10^{-10}$	$<3.6 \times 10^{-10}$
6	Outer Diaphragm to Piston	$<3.4 \times 10^{-10}$	8.9×10^{-5}	4.3×10^{-6}
7	Closure Assembly Hub Detail	$<2.5 \times 10^{-8}$	$<2.7 \times 10^{-10}$	$<3.3 \times 10^{-10}$
8	Maraging Steel Shell to Closure	$<3 \times 10^{-10}$	$< 2.4 \times 10^{-10}$	$< 3.7 \times 10^{-10}$
9	Maraging Steel Inner Support Tube to Closure			

(9108-31)
Figure 24. Rolldex Outer Diaphragm Leak Test

The test method, conditions of test, instrumentation and a schematic of the test setup are included in RMD Test Plan Specification 1452, appended to this report.

Figures 25 and 26 provide an overall and internal view of the tank assembly after the hot gas demonstration test. The tank closure has been removed by machining away the weld to permit viewing the gas side of the Rolldex. As can be seen in Figure 26 the Rolldex assembly was in excellant condition after the test. A gas leak test of the unit to a level of 400 psia after the test showed no leakage.

Pertinent results of the demonstration test are summarized in Table IV. Figure 27 is a reproduction of the test log sheet for the test. As the test results indicate, the measured rolling pressure was 9 psid versus the required 10 psid maximum and the measured expulsion efficiency within the accuracy of the test data was 99.8%.

Because the demonstration test was conducted in the nozzle down position, and the tank was vacuum filled in a closed system, it was not possible to determine if the tank was completely filled with water and hence not possible to assess volumetric efficiency from the demonstration test data. Volumetric efficiency is defined as:

$$N_V = \frac{\text{Volume of Propellant Expelled}}{\text{Internal Volume of Tank Shell}} \times 100$$

Since the demonstration test did not permit assessment of volumetric efficiency, this efficiency was calculated on the basis of the tank assembly dimensions. The internal volume of the maraging steel tank shell was calculated to be 23,769 in.^{3}. This value is based on the volume formed by the outer shell and forward and aft closures (Figure 4) and assumed no center support tube. If the 305 in.^{3} volume occupied by the center support tube is taken into consideration, the internal volume of the tank shell is 23,464 in.^{3}. The calculated volume inside the Rolldex available for propellant (including 0.5% ullage allowance) is 22,288 in.^{3}. On this basis volumetric efficiency was calculated to be 93.77% if the volume occupied by the center tube is not taken into consideration and 95% if the volume occupied by the center tube is considered. Required volumetric efficiency is 95%.

On the basis of the above calculations and demonstration test results, it was concluded that the positive expulsion tank assembly design satisfactorily met design requirements with the possible exception of volumetric efficiency. Improvement of volumetric efficiency is possible in the design to the point where a 95% efficiency is achievable even if the center tube volume is not taken into consideration by a recontour of the tank headers and Rolldex piston to provide a better nesting (See Figure 4) on the gas side of the piston.

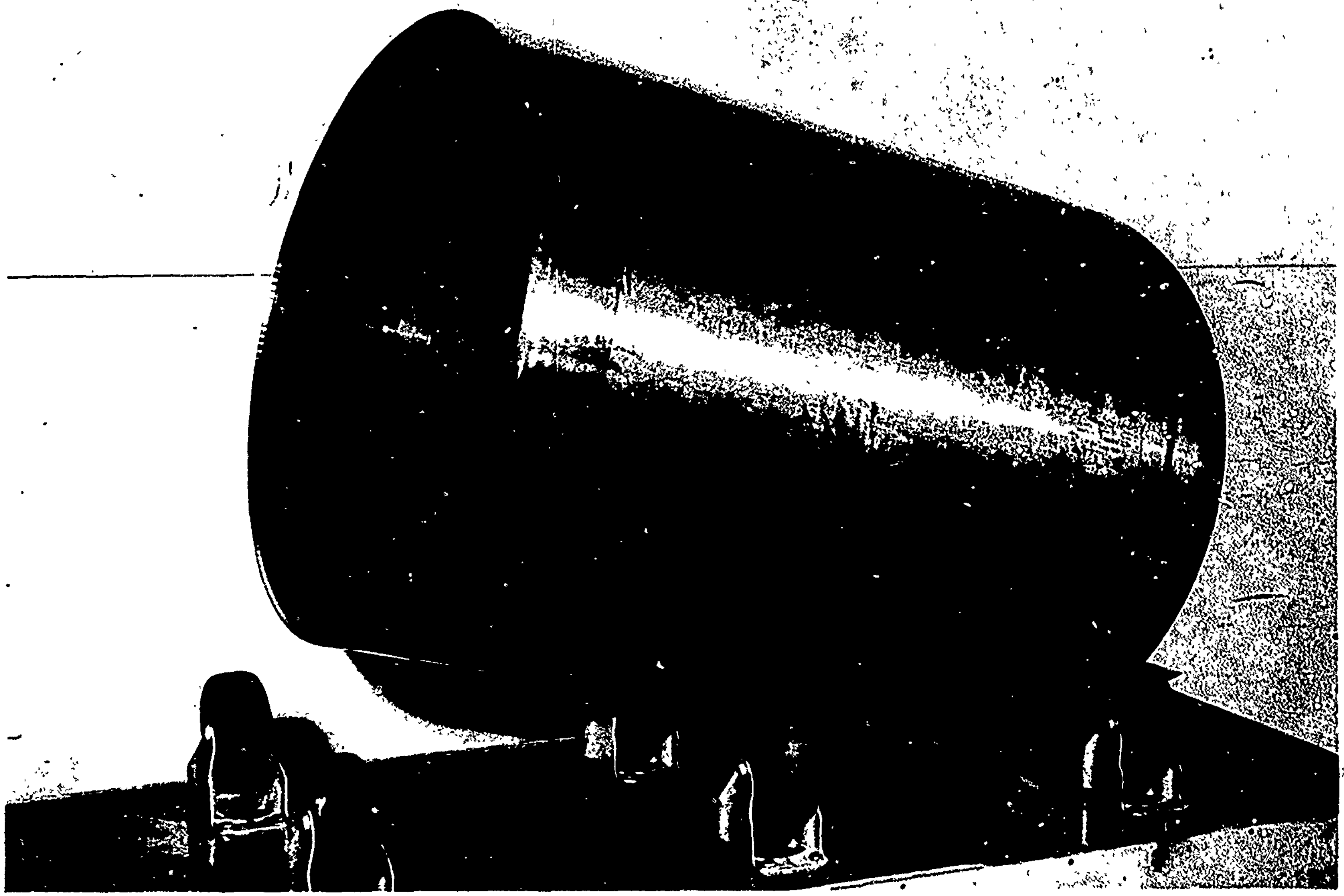


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Figure 25. Overall View of 318273 Expulsion Tank Assembly after Hot Gas Test

(6059-8)

Figure 26. Internal View of 318273 Expulsion Assembly After Hot Gas Test

TABLE IV

DEMONSTRATION TEST RESULTS

Operating Tank Pressure (psia)	371 to 407
Pressurizing Gas Inlet Temperature (°F)	900 to 1010
Average Water Flowrate (lb/sec)	2.55
Run Duration (sec)	302
Rolling Pressure (psid)	9.0
*Expulsion Efficiency (%)	99.87

$$\text{*Expulsion Efficiency} = \frac{\text{Volume of Propellant Expelled}}{\text{Volume of Propellant Loaded}} \times 100$$

TEST LOG SHEET

REACTION MOTORS, DIV., DENVILLE, NEW JERSEY

TEST STAND NUMBER S 12A	FUEL N_2H_4	PAGE NUMBER 1 OF 1 PAGES
TEST RUN NUMBER S 12A 2X 57	OXIDIZER	DATE 12-13-68 TIME
TEST OPERATOR R. Hardy	Decomposed N_2H_4 on Gas Side COOLANT	T. W. R. NUMBER
TEST ENGINEER R. Marvinney	OTHER H_2O on Liquid Side	PROJECT NUMBER 6059 / PHASE 60
Prod. Engr. T. O'Grady	ENGINE OR PART NO. 318273-100	CODE 1000
CUSTOMER INSPECTOR	GG Part No. X318426 (modified) T. P. 1452	

OBJECT: Design Demonstration Test

Prerun Comments:

(1) Condor Workhorse type gas generator with thermal bed assembled as follows: (65) 20 x 20 screens (6) 14 x 14 screens (2) downstream O-ring adapters with O-rings (125 GR) I_2O_5 in unsealed package.

(2) Press. SW. set at 400 psig (range is 380 to 425 psig)

(3) Purge setting: 445 psig

(4) Bleed at 50 psig tank press

(5) H_2O vacuum loaded: (2 psia) liquid side/(1.0 psia) gas side
Loading rate: 17 lbs/min max

(6) 2000 lb Cap. load cell (tension) used for weighing

TEST DATA

Loaded Weight (lbs)		1629
Dry Weight (lbs)	Prerun	859
H_2O Loaded (lbs)		770
Expulsion Tank Liq Side Flow Total Cy Count		73,559
Expulsion Tank Liq Side Flow Factor		0.01045523 lb/cy
Expulsion Tank Liq Side Flow Total (lbs)		769
Total Duration (sec)		302
Steady State Exp. Tank Inlet Temp ($^\circ$F)		900 to 1010
Steady State Exp. Tank Inlet Press (psia)		371 to 407
Steady State Exp. Tank Outlet Temp($^\circ$F)		50 to 60
Steady State Exp. Tank Rolling ΔP (psi)		9.0

Postrun Comments:

(1) Exp. tank water flushed and returned to Manufacturing for disassembly

T L S 1 (12/66)

Figure 27. Sample Test Log Sheet

SECTION V

CONCLUSIONS

Based on the results of the analyses of the tank assembly design and the results of the laboratory, helium leak and hot gas expulsion (demonstration) tests, it is concluded that the delivered tank assemblies will meet all specified technical requirements. Utilization of the delivered assemblies in the AFRPL storability program will provide significant data on the correlation of mass spectrometer helium leak test results with propellant containment during long term storage.

SECTION VI

REFERENCES

1. JPL Contract No. 950997 for Thiokol-RMD Thrust Chamber Assembly TD-339.

2. D. J. Santeler and T. W. Moller, Fluid Flow Conversion in Leaks and Capillaries, Vacuum Society Transactions, 1956. J. W. Marr, "Study of Dynamic and Static Seals for Liquid Rocket Applications," Appendix G, NASA Advanced Technology Contract No. NAS 7-102, 1964.

3. R. S. Weiner, Gas to Liquid Leakage Correlation, JPL Analysis Report No. 65X03100, 1965.

4. Martin-Denver, Report CR64-145, on Contract No. AF04(647)-576.

5. R. S. Weiner, Jet Propulsion Laboratory Technical Report No. 23-926, December 1966.

6. J. W. Marr, Leakage Testing Handbook, Prepared for Liquid Propulsion Section, Jet Propulsion Laboratory, NASA Contract NAS 7-396, June 1957.

APPENDIX

RMD SPECIFICATION 1452

PROCEDURE FOR
30-INCH DIAMETER N_2O_4 EXPULSION TANK
DESIGN DEMONSTRATION TEST

Thiokol CHEMICAL CORPORATION
REACTION MOTORS DIVISION
DENVILLE, NEW JERSEY

SPEC. 1452

SPECIFICATION 1452

CLASS III PG. 1 OF 7 LET. A

30-INCH DIAMETER N_2O_4 EXPULSION TANK DESIGN DEMONSTRATION TEST, PROCEDURE FOR

LET.	REL. NO.	DATE	CHANGE	CHK.	APP.

Orig.	E. I. C.	Design	Stress	Mgr. Eng.	Q.C.				REL. NO.
Tobler	Tobler	TWS	C. [illegible]	R. [illegible]	S. Kahn				6059-
12-9-68	12-9-68	12-9-68	12-9-68	12/9/68	12/10/68				73

RMD RE33C (11/66)

1.0 SCOPE

This specification describes the procedures necessary for the conduct of design demonstration test (hot gas water expulsion test) to verify the volumetric efficiency, expulsion efficiency, and actuation pressure of the 318273 N_2O_4 Positive Expulsion Tank Assembly.

2.0 APPLICABLE DOCUMENTS

RMD Drawings

318273 N_2O_4 Positive Expulsion Tank Assembly
318264 Shell and Head Assembly, Tank
318266 Closure Assembly

MT 13145 Volumetric Test Rig

3.0 REQUIREMENTS

3.1 General

The procedures described herein are provided to conduct a design demonstration test (hot gas water expulsion test) of a rocket propellant tank with an integral expulsion (Rolldex) device intended for long term storage and positive expulsion of Nitrogen Tetroxide (N_2O_4). Test results will be used to assess the following:

a. Expulsion Efficiency
b. Volumetric Efficiency
c. Actuation Pressure

3.2 Test Items and Apparatus

The 30-inch diameter positive expulsion tank assembly to be tested is defined by RMD Drawing 318273. The tank assembly shall be installed in the MT 13145 Volumetric Test Rig and installed in the test stand in a vertical nozzle down (propellant outlet port down) position. A schematic of the test installation is given in Figure 1.

3.3 Test Conditions

Attitude:	Tank centerline shall be vertical, with liquid outlet port down.
Temperature:	Normal ambient.
Test Fluid:	Water which shall contain 0.01 to 0.02% by weight potassium chromate inhibitor.
Pressurizing Fluid:	Hot gas decomposition products from a thermal bed monopropellant gas generator using N_2H_4 fuel.
Operating Pressure:	400 psig
Test Duration:	Approximately 275 seconds

3.4 Instrumentation and Data Acquisition

For the conduct of the test, instrumentation shall be provided for measurement of the parameters noted in Table I. Instrumentation locations are noted on Figure 1. Data shall be recorded on Brown and/or oscillograph type recorders.

3.5 Expulsion Efficiency

Expulsion efficiency shall be determined on the basis of the hot gas expulsion test. The ratio of the weight of water expelled over the weight of water loaded expressed as a percentage is the expulsion efficiency.

TABLE I

INSTRUMENTATION REQUIREMENTS

Expulsion Tank Inlet Pressure	0-500 psig
Expulsion Tank Outlet Pressure	0-500 psig
Rolldex Rolling P	0-25 psid
Expulsion Tank Inlet Gas Temperature	0-1200 F.
Expulsion Tank Outlet Liquid Temperature	0-100 F.
Expulsion (Water) Flowrate	0-4 lb/sec.
Tank Outlet Control Orifice Inlet Pressure	0-500 psig
Tank Outlet Control Orifice Outlet Pressure	0-500 psig
Tank Weight (Load Cell)	200 - 1200 lb.
Gas Generator Liquid Flowrate	0 - .2 lb/sec.
Gas Generator Liquid Flowmeter Inlet Temperature	0 - 100 F.
Gas Generator Venturi Inlet Pressure	0 - 500 psig
Gas Generator Inlet Pressure	0 - 500 psig
Gas Generator Outlet Pressure	0 - 500 psig
Gas Generator Outlet Temperature	0 - 2000 F.

3.6 Volumetric Efficiency

Volumetric efficiency shall be determined on the basis of the results of the Expulsion Efficiency and Water Expulsion Test. The weight of water expelled shall be converted to volume through hydrometry at the test temperature of the water. The ratio of this volume to the internal volume of the tank shell (22288 in^3) expressed as a percentage is the volumetric efficiency.

4.0 QUALITY ASSURANCE PROVISIONS

4.1 Test Procedure

4.1.1 Gas Generator Checkout

Prior to the conduct of the hot gas water expulsion test, a checkout test of the gas generator system shall be conducted to assure that the hot gas conditions at the inlet to the expulsion tank assembly are 400 psig and 1000F. nominal, at a flowrate of 0.2 ± .03 lb/sec.

4.1.2 Loading Procedure

With the unit installed in the test setup and satisfactorily pressure checked, the gas side of the Rolldex piston shall be evacuated to a pressure no greater than 0.5 psia. The vacuum pump shall be removed and the vacuum maintained in the system. The expulsion tank assembly shall then be vacuum loaded with water. A vacuum loading pressure of 1-2 psia is acceptable. The weight of water loaded shall be recorded. The tank shall be loaded to capacity.

4.1.3 Test Sequence

4.1.3.1 Starting Sequence

With the instrumentation recorders operating, the tank system shall be pre-pressurized with nitrogen to 400 psig simulating a missile arming sequence. This operation will cause the burst disc at the tank outlet to rupture and allow water to flow to the electrically actuated propellant valve. The gas generator shall then be started, and the propellant valve actuated permitting water to flow from the expulsion tank.

4.1.3.2 Running Sequence

The gas generated by the thermal bed will cause the Rolldex piston to continue to move until all water has been expelled. Hot gas (1000F) at 400 psi is required. The system must be calibrated to provide the required flow (equivalent volumetric flowrate of demineralized water corresponding to 4 lb/sec. of N_2O_4).

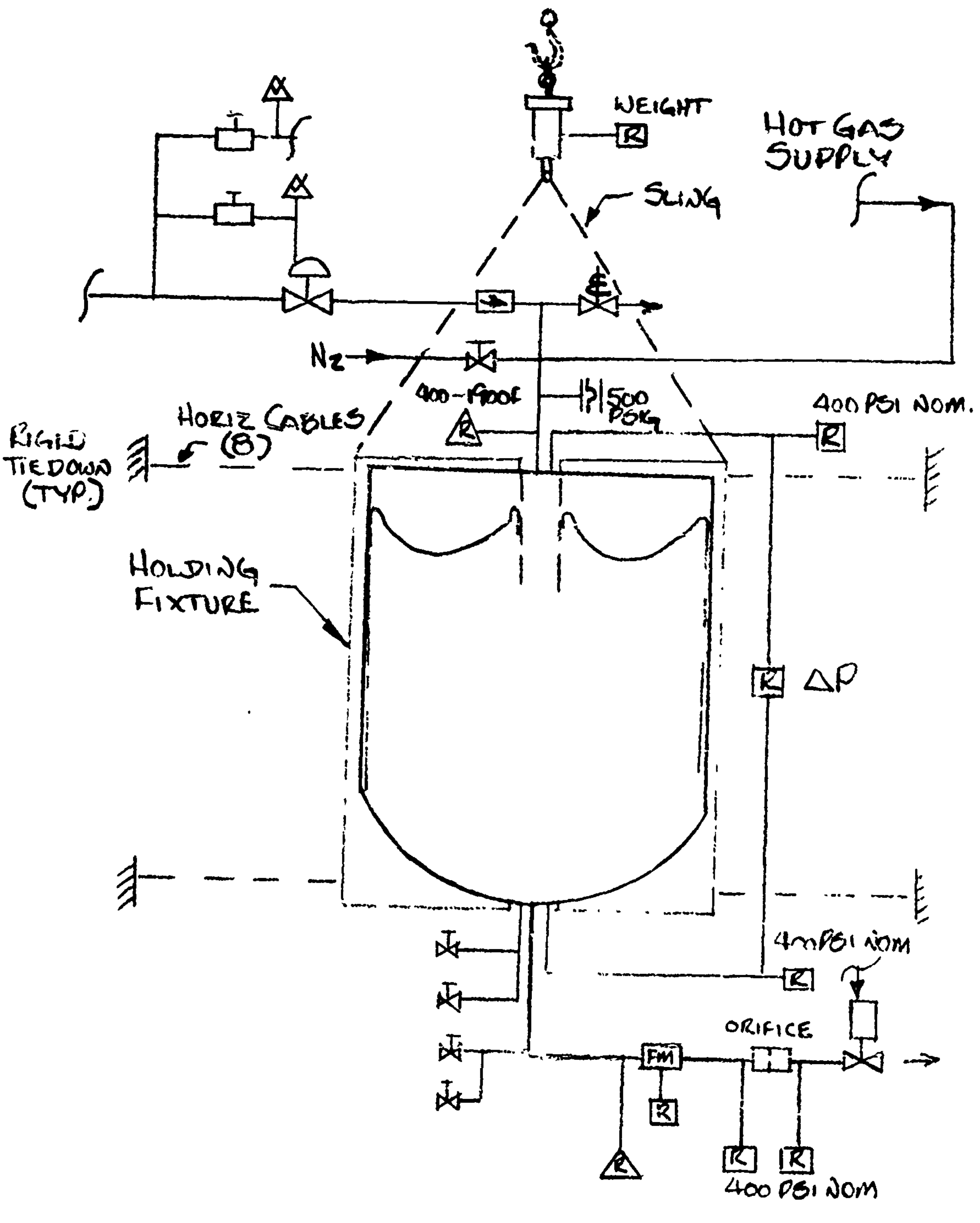
The test will be continued until all the water has been expelled from the system. The weight of water expelled shall be recorded. Gas pressure is to be maintained in the system for a minimum period of five minutes following which the system shall be vented. The tank assembly shall then be removed from the test stand and delivered to manufacturing for subsequent disassembly. A secondary (nitrogen) pressurization system shall be provided to pressurize the tank in the event the gas generator malfunctions and a gas diluent to regulate the gas inlet temperature. The nitrogen shall be regulated to a pressure 15 psi lower than the gas generator pressure.

5.0 PREPARATION FOR DELIVERY

Not applicable.

6.0 NOTES

Not applicable.



30" TANK ASS'Y
TEST SCHEMATIC

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13. ABSTRACT This report describes the results of a program to design, evaluate and deliver full scale, flight-weight positive expulsion propellant tank systems for inclusion in the AFRPL storability program. The tank system has a diameter of 30 inches; an overall length of 43.4 and is sized for a total capacity of 1100 lb of N_2O_4. The cylindrical design is comprised of a maraging steel (250 grade) outer shell inside of which is installed an all-aluminum ~~Rolldex~~ (rolling diaphragm) positive expulsion system. The Rolldex expulsion system consists of cylindrical inner and outer diaphragms, an annular piston with integral hub guide, and a convex dome. The outer and inner diaphragms are bonded to the tank wall and center support tube, respectively. During expulsion, the annular piston traverses the full length of the tankage, rolling the diaphragms as it goes and thus parting the bonds. All materials of construction are compatible with N_2O_4 for long term storage. The materials used are 1100-0 and 6061-T6 aluminum, 250 grade maraging steel and Teflon. A succession of barriers throughout the assembly eliminates the possibility of leakage. Special provisions are made at the fill and load ports to prevent leakage at these points. Detailed thermal and structural analyses were performed, as well as laboratory tests to verify critical design parameters. A test phase was conducted, consisting of a successful hot gas expulsion test to demonstrate the design under operational environments, followed by fabrication and delivery of units for inclusion in the AFRPL storability program.

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